FEDERATION OF SEWAGE WORKS ASSOCIATIONS

OFFICERS

Chairman

C. A. EMERSON, JR., Fuller and McClintock, 11 Park Place, New York, N. Y.

Vice-Chairman

JULIUS W. BUGBEE, Supt., Sewage Disposal Works, 25 New York Ave., Providence, R. I.

Secretary-Treasurer

H. E. MOSES, Assistant Chief Engineer, Pennsylvania State Department of Health, Harrisburg, Pa.

Business Manager

WM. W. BUFFUM, General Manager, The Chemical Foundation, 654 Madison Ave., New York, N. Y.

Editor

F. W. MOHLMAN, Chief Chemist, The Sanitary District of Chicago, 845 S. Wabash Ave., Chicago, Ill.

Board of Control

ALBERT E. BERRY, Toronto, Canada
E. B. BESSELIEVRE, New York City
FLOYD G. BROWNE, Marion, Ohio
WM. W. BUFFUM, New York City
C. K. BULLEN, Blackwell, Okla.
ANSELMO F. DAPPERT, Albany, N. Y.
H. J. DARCEY, Oklahoma City, Okla.
F. H. DRYDEN, Salisbury, Md.
V. M. EHLERS, Austin, Texas
C. A. EMERSON, JR., New York City
LEWIS S. FINCH, Indianapolis, Ind.
L. M. FISHER, New York City
RALPH FUHRMAN, Springfield, Mo.
JOHN H. GARNER, Wakefield, Eng.
C. G. GILLESPIE, Berkeley, Calif.
E. S. GLENN, Carthage, Mo.
GUY E. GRIFFIN, Greenwich, Conn.
A. D. HAMLYN, London, Eng.
R. C. HARRIS, Toronto, Canada
CHARLES G. HYDE, Berkeley, Calif.
ROY S. LANPHEAR, Worcester, Mass.
MAX LEVINE, Ames, Iowa
W. S. MAHLIE, Fort Worth, Texas
C. D. MCGUIRE, Columbus, Ohio
H. E. MOSES, Harrisburg, Pa.
LINDON J. MURPHY, Ames, Iowa
H. A. OLSON, Ann Arbor, Mich.
WM. J. ORCHARD, Newark, N. J.
EARLE B. PHELPS, New York City
WM. M. PIATT, Durham, N. C.
MISS JANE H. RIDER, Tucson, Ariz.
A. M. RAWN, Los Angeles, Calif.
WILLEM RUDOLFS, New Brunswick, N. J.
JAMES R. RUMSEY, Grand Rapids, Mich.
RICHARD C. SMITH, Glen Ridge, N. J.
H. W. STREETER, Cincinnati, Ohio
E. C. SULLIVAN, Cincinnati, Ohio
GODFREY M. C. TAYLOR, London, Eng.
DARIO TRAVAINI, Phoenix, Ariz.
L. F. WARRICK, Madison, Wis.
J. S. WHITENER, Raleigh, N. C.
ABEL WOLMAN, Baltimore, Md.

SEWAGE WORKS JOURNAL

REG. U. S. PAT. OFF.

A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

Publication Office: Prince and Lemon Sts., Lancaster, Pa.

Editorial Office: 845 S. Wabash Ave., Chicago, Ill.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $1.00 per year.

Non-members: Total fee $3.00, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50 per year; other countries, $4.00 per year.

Foreign Subscriptions must be accompanied by International Money Order.

Single copies: United States, $1.00 each; Foreign, $1.25 each.

Manuscript may be sent to the Editor, F. W. Mohlman, 845 S. Wabash Ave., Chicago, Ill., for acceptance or rejection subject to the provisions of the Federation constitution.

Subscriptions, advertising copy and address changes should be sent to the Business Manager's Office at Lancaster, Pa., or at 654 Madison Ave., New York, N. Y.

No claims will be allowed for copies of Journals lost in the mails unless such claims are received within sixty (60) days of the date of issue and no claims will be allowed for issues lost as a result of insufficient notice of change of address. "Missing from files" cannot be accepted as the reason for honoring a claim.

Entered as second-class matter, May 7, 1934, at the post office at Lancaster, Pa., under the Act of March 3, 1879.

This matter of economy

The cost of mechanical, processing equipment seldom exceeds 10 to 15 per cent of cost of a complete sewage plant. Consequently the reduction of the expenditure for machinery to the absolute minimum seldom of itself assures an economical design.

Birmingham, Ala.—Ensley Plant—Designed by Harry H. Hendon, Sanitary Engineer, Jefferson County, Ala. Fuller & McClintock, Consulting Engineer.

The cost of treatment per million gallons, day in and day out, is the accepted criterion of economy among experienced engineers.

The four plants pictured here are leaders of their type from the standpoint of economy. Two use the activated sludge process, one separate digestion and one chemical precipitation.

Newark, N. Y.—Glenn D. Holmes, Consulting Engineer

Significantly all use DORR equipment—seldom the cheapest on a factory basis. Significantly, too, the costs tabulated below show that the premium paid for better equipment has been more than justified.

Economy on an installed and operating basis—not mere low price of bare equipment—has been the keystone of DORR engineering policy from the beginning.

DORRCO

	TYPE	DESIGN FLOW MGD	OPERATING COST MG	DORR EQUIPMENT USED				
				BAR SCREENS	DETRITUS	ALTIMETER	DIGESTER	AERATOR
PHOENIX, ARIZ	A.S.	12	$11.71	*	*	*	*	*
NEWARK, N.Y.	A.S.	1.5	14.52			*	*	*
BIRMINGHAM, ALA. ENSLEY	C.P.	2	9.30	*		*	*	
BIRMINGHAM, ALA. ENSLEY	S.D.	15	2.60	*	*	*	*	

1 - A.S. - ACTIVATED SLUDGE TREATMENT FOLLOWED BY SLUDGE DIGESTION
C.P. - CHEMICAL PRECIPITATION
S.D. - SEDIMENTATION, SEPARATE SLUDGE DIGESTION, TRICKLING FILTER

Phoenix, Ariz.—Clyde C. Kennedy, Consulting Engineer

Birmingham, Ala.—Shades Valley Plant—Designed by Harry H. Hendon, Sanitary Engineer, Jefferson County, Ala.

THE DORR COMPANY, Inc.

Engineers · 247 Park Ave., New York

Chicago Denver Los Angeles Toronto

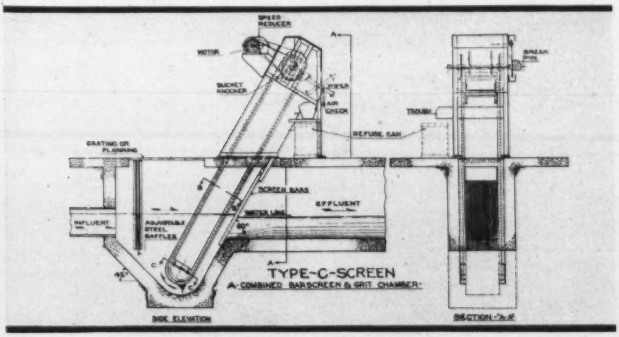
[Short Talks with Sewage Plant Designers]

How Much GRIT Have You?

MINERAL grit and other detritus may be awfully troublesome—say in sedimentation tanks, and especially in Imhoff tanks. If it settles in an inverted siphon or flat grade in a sewer system, a lot of money and trouble may be required periodically for removing it.

For it is heavy stuff to handle, and unless removed frequently, is apt to pack down solid, while the organic matter in it putrefies. And a grit chamber or pit is pretty sure to do one of two things—probably both; fail to hold back all the detritus, or retain with it considerable organic matter.

A Link-Belt type "C" combined screen and grit chamber will catch the grit, and will remove it before it compacts, or the organic matter putrefies. And it does this mechanically and automatically. Moreover "it works while you sleep", and many of the storms that flush grit deposits into the sewer, or into the plant, occur at night.



LINK-BELT COMPANY
Leading Manufacturers of
Equipment for Handling Materials Mechanically and Transmitting Power Positively
PHILADELPHIA, 2045 West Hunting Park Avenue CHICAGO, 300 West Pershing Road
SAN FRANCISCO, 400 Paul Ave. TORONTO, Eastern Ave. & Leslie St. Offices in Principal Cities

LINK-BELT 4695-A

SCREENS ▲ COLLECTORS
AERATORS ▲ GRIT CHAMBERS ▲ DISTRIBUTORS

CHAIN BELT COMPANY

Rex Mechanically Cleaned (Power) Bar Screen, plant of City of Oneonta, N. Y. Note full enclosure of entire unit and ease with which screenings are removed. Clyde Potts, Consulting Engineer, New York.

REX Mechanically Cleaned Bar Screens
Fully Enclosed... Accessible... Long Lived

In furnishing the Rex Mechanically Cleaned (Power) Bar Screen for the sewage plant of the city of Oneonta, N. Y., Chain Belt Engineers met the specification of the consulting engineer for a bar screen as neat in appearance as the balance of the plant. No sacrifice was made in efficiency nor in the convenience of removing the screenings.

Rex Bar Screens are fully enclosed, permitting strong construction and improved appearance. The rolled bronze screening plates, with milled slots, are attached to Rex Z-Metal Chains driven by an anti-friction motor unit. These chains provide added strength and much greater resistance to corrosion and abrasion than malleable chains. The result is a more efficient bar screen, which is easily accessible and much longer lived.

Full information will be furnished consulting engineers, officials and operating engineers.

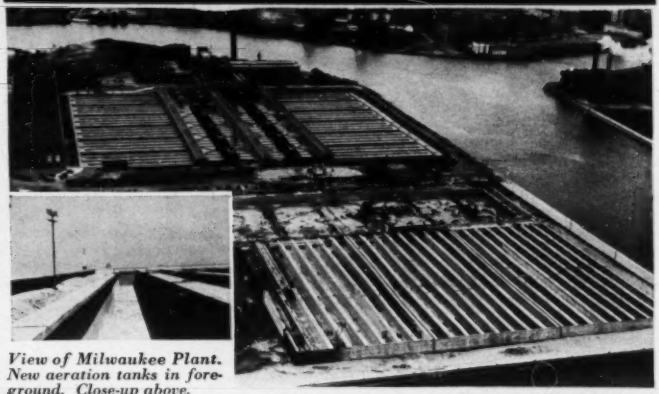
CHAIN BELT COMPANY, 1606 WEST BRUCE STREET, MILWAUKEE, WIS.

Sewage — Trade Wastes — Water Treatment — Sludge Removers — Screens — Sludge Pumps

REX SANITATION EQUIPMENT

Established 1891 — Branches or Representatives in all Principal Cities

13,500
ALOXITE BRAND DIFFUSER PLATES
selected for Milwaukee's
Sewage Treatment Plant Extension



View of Milwaukee Plant. New aeration tanks in foreground. Close-up above.

Photo, Courtesy Milwaukee Journal

A further evidence of the ability of these diffusers to meet the most exacting specifications for:

PERMEABILITY... UNIFORMITY... PRESSURE LOSS... STRENGTH... DIMENSIONS AND SHAPE... INERTNESS

ENGINEERS of the Sewerage Commission of the City of Milwaukee and all engineers throughout the country recognize the importance of choosing none but the best product for the important function of air diffusion—the heart of the plant—where they "make or break" plant efficiency. To insure proper selection of diffusers for your project, utilize the services of our Sanitary and Filtration Department—directed by trained Sanitary Engineers.

THE CARBORUNDUM COMPANY, NIAGARA FALLS, N. Y.

CANADIAN CARBORUNDUM CO., LTD., NIAGARA FALLS, ONT.

(CARBORUNDUM AND ALOXITE ARE REGISTERED TRADE MARKS OF THE CARBORUNDUM COMPANY)

MINIMIZING CORROSION

● In practically every spot where metal must be used in the sewage disposal plant, Alcoa Aluminum will give long satisfactory service, save expensive maintenance, and look better, too. All for the simple and inescapable reason that Alcoa Aluminum is *more* resistant to corrosion.

★ INSIDE AND OUT ★

● Corrosion, corrosion, corrosion! From the front door knob to the bottommost inch of the tanks, the teeth of corrosion are bared for action every minute. How well you know it. How costly it is! But Alcoa Aluminum resists that corrosion. Tests under all sorts of conditions prove it. Experience demonstrates it.

IMMERSED OR EXPOSED

● Alloys with all necessary strength characteristics are available in every form needed for immersed or exposed applications. The cost is so reasonable that Alcoa Aluminum should be in every metal specification ...Do you have our book "Aluminum in Sewage Disposal Plants?"

ALUMINUM COMPANY OF AMERICA
1811 Gulf Building, Pittsburgh, Pa.

ALCOA ALUMINUM

"U. S." Ferric Chloride "Permobond" Tank and Pipe Lining

11 years' service in Milwaukee, Indianapolis and Chicago Sewage Disposal Plants

Ferric Chloride tanks and piping at the Stickney plant of the Chicago Sanitary District are lined with U. S. Ferric Chloride Permobond.

These 12,000 gallon Ferric Chloride storage tanks at the Milwaukee Sewage Disposal Plant, measure 11 feet in diameter by 10 feet, 6 inches in height. Both are lined with "U. S." Ferric Chloride Permobond.

THE comparatively recent adoption of Ferric Chloride as a sewage coagulant presented a corrosive problem which could best be solved with rubber.

More than five years ago "U. S." Rubber Engineers were called upon to develop an efficient, economical anti-corrodent.

They answered the call with "U. S." Ferric Chloride Permobond lining.

The Sewage Department of the city of Milwaukee was first to order Ferric Chloride storage tanks, piping and fittings, lined with this new "U. S." development. The city of Indianapolis followed suit one year later, and two years ago the Chicago Sanitary District installed "U. S." Ferric Chloride Permobond at its Stickney plant.

With this total of 11 years of service "U. S." Ferric Chloride Permobond has conclusively proven its superiority. *It has been subjected to longer service than any other rubber lining.*

THE United States Rubber Company is the World's Largest Producer of mechanical rubber goods . . . makes the Most Complete Line . . . maintains the Greatest Research Laboratories . . . and offers to industry a Technical Engineering Service of the Broadest Experience.

"U. S." Ferric Chloride Permobond can be applied to wood or metal . . . tanks, pipe and fittings.

"U. S." Engineers will welcome the opportunity to cooperate with you in solving your Ferric Chloride problems. A phone call or letter will bring a representative without obligation.

United States Rubber Company

1790 BROADWAY NEW YORK CITY

BRANCHES IN ALL INDUSTRIAL CENTERS

THE ULTIMATE
in Sewage Coagulants

ANHYDROUS
FERRIC CHLORIDE
NOW *Commercially Available*

THE Pennsylvania Salt Manufacturing Company was the first to produce Liquid Ferric Chloride at a price within the reach of sewage plants.

Again the Pennsylvania Salt Manufacturing Company is the first to offer Anhydrous Ferric Chloride in a form suitable for plants which have not found it practical to use Ferric Chloride in the past, because of their geographic location, lack of railroad siding facilities or limited consumption.

Anhydrous Ferric Chloride comes in powdered form. It is packed in air-tight, non-returnable steel drums . . . Is instantly soluble . . . And can be stored indefinitely without deterioration or liquefaction.

Write for samples. Physical and chemical specifications gladly furnished upon request.

PENNSYLVANIA SALT MFG. CO.

EXECUTIVE OFFICES, WIDENER BLDG., PHILADELPHIA, PA.

Branch Sales Offices: New York, Chicago, St. Louis, Pittsburgh, Tacoma, Wyandotte

EVERDUR METAL

stands on its enviable record in Sewage Treatment Works

Combines corrosion-resistance and high strength with ease of fabrication and reasonable cost

Double Type Slide Gate of Everdur Each slide is 18" x 60" and is made of ⅜" Everdur plate with grooves in slide. Illustration below shows slide gates in actual service.

EVERDUR might have been designed especially for the sewage treatment field, so ideally does it meet the requirements of this service. Since 1927 it has been used for basket screens, slide gates, and other parts exposed to sewage corrosion, and in every application shows uniform excellent corrosion-resistance and every indication of permanence.

This copper alloy possesses the strength and physical properties of mild carbon steel. It is comparatively inert, resists many industrial corrosive agents and will not season-crack.

Everdur is produced in all commercial forms and is easily fabricated by usual steel procedures, including welding. Engineers who have used Everdur in sewage treatment works are agreed that it is the logical solution to many corrosion problems.

EVERDUR METAL

"Everdur" is a registered trade-mark identifying products of The American Brass Company made from alloys of copper, silicon and other elements.

Everdur Adjustable Outlet Weir. Frame is of cast and machined Everdur angles, weir is of ¼" Everdur plate, operating stem is of 1½" threaded Everdur rod.

ANACONDA
from mine to consumer

THE AMERICAN BRASS COMPANY

General Offices: Waterbury, Conn.

Offices and Agencies in Principal Cities

ANACONDA COPPER & BRASS

Now!

Variable Speed
Screw-Feed Sludge Pump

Centrifugal—Will Not Clog

Capacity varied instantly
From 1 G.P.M. to Max. of Pump
by merely turning wheel on varidrive motor.
Indicator shows capacity.

Fig. 1847—Screw-Feed Centrifugal Pump with varidrive motor.

CHICAGO PUMP COMPANY
SEWAGE-CONDENSATION-CIRCULATING
BILGE-FIRE-HOUSE-VACUUM

2300 Wolfram Street BRUnswick 4110 CHICAGO

Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Copyright, 1934, by Federation of Sewage Works Associations

Vol. VI July, 1934 No. 4

Sewage Research:

Settling and Compacting of Activated Sludge. By Willem Rudolfs and I. O. Lacy 647

Bacterial Numbers in Activated Sludge Mixtures. By H. Heukelekian.. 676

Adsorption and Flocculation as Applied to Sewage Sludges. By A. L. Genter 689

Tendencies in Standards of River and Lake Cleanliness. By H. W. Streeter 721

The Relation of the pH of Dilution Water to the Biochemical Oxygen Demand of Various Wastes. By J. M. Holderby and Wm. L. Lea..... 734

Sewage Works Operation:

Two Years Operating Experience of Modern Chemical-Mechanical Sewage Treatment, Dearborn, Michigan. By Mark B. Owen 742

Paints for Sewage Works. By W. T. McClenahan 762

Experiments with Inlet Devices for Sedimentation Tanks. By George E. Hubbell 774

Chlorine Disinfection of Sewage. By Warren J. Scott and Le Roy W. Van Kleeck 784

Tipping Sludge Bucket Meter Developed at Aurora, Illinois. By Walter A. Sperry 797

A Simple Device for Sampling Sludge. By Dr. H. Bach 803

Editorial:

The Dearborn Plant. By F. W. Mohlman, *Editor* 805

George W. Fuller. By F. W. Mohlman, *Editor* 807

Proceedings of Local Associations:

California Sewage Works Association. Sixth Annual Spring Conference. 809

The Maryland-Delaware Water and Sewerage Association. Eighth Annual Conference 814

New York State Sewage Works Association. Spring Meeting 816

Reviews and Abstracts:

Report of the (British) Water Pollution Research Board for the Year Ended 30th June, 1933. By H. T. Calvert 820

Forty-first Annual Report, the West Riding of Yorkshire Rivers Board (Wakefield, England). By John Garner 823

Sewage Treatment at Sutton and Cheam. By William H. Grieves 825

The Removal of Phenols from Sewage by Means of Compressed Air. By Prof. Dr. A. Schulze-Forster and Dr. L. W. Haase 826

The Causes of Sewer Gasification. By Dipl. Ing. K. Dau 828

The Construction of Sewage Fish Ponds as Relief Work. By Th. Falck.. 829

Building Sewers Under Difficult Conditions. By F. C. Ziegler 831
Sewage Disposal at Fort Atkinson, Wisconsin. By Robert Cramer 832
Determining the pH of Sewage Sludge. By Morrill Dakin 833
Drying and Incineration of Sewage Sludge. By Alden E. Stilson 833
Sludge Thickening at Phoenix, Arizona. By D. Travaini 834
Operation of Pruss Pump at Baltimore Sewage Works. By C. E. Keefer 835
Dewatering Sewage Sludge by Vacuum Filters at Hagerstown, Maryland. By Wellington Donaldson 836
Sewage Treatment Developments in Continental Europe. By Willem Rudolfs 836
Sewage Disposal in Britain. By F. Johnstone-Taylor 838
Controlling Sludge Level 838
Checking Corrosion. By R. C. Wilson 839
Small Sewage Treatment Plants. By W. Scott Johnson 839
Description of Sewage Treatment Plant at Flint, Michigan 840
Sewage Clarification at Rockville Center, N. Y. 840

JOIN YOUR STATE OR LOCAL SEWAGE WORKS ASSOCIATION

AFFILIATE WITH THE NATIONAL FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Members of the Federation receive

THE SEWAGE WORKS JOURNAL

for one dollar per year

Non-members' subscription fee $3.00 per year, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50; other countries, $4.00.

Send Subscriptions to

WM. W. BUFFUM, Business Manager
654 Madison Ave.
New York, N. Y.

Sewage Research

SETTLING AND COMPACTING OF ACTIVATED SLUDGE*

By Willem Rudolfs and I. O. Lacy

Chief and Assistant, Division Water and Sewage Research, New Jersey Experiment Station

In several instances experiments have been conducted dealing with certain factors affecting the rates of settling and concentration of activated sludges, but a search of the literature does not reveal that a systematic study has been made to ascertain the effects of a number of factors which may play a rôle. Perhaps the most outstanding early contribution was made by Pearse (1) who concluded that the subsidence of activated sludge depends upon the state of activation, physical character, moisture content and temperature. Experiments indicated that concentration would be more rapid in shallow than deep tanks. About the same concentration of sludge could be effected in a 100 c.c. cylinder at a 60° angle in 20 minutes as in 60 minutes with the cylinder vertical. Townsend (2), discussing the settling characteristics of activated sludge, states that "there are four major controlling factors which determine the settling capacity or ability of a continuous-flow tank of given dimensions and volume." He concludes that the depth of the sludge concentrating zone in the tank should be in proportion to the solids concentration. The effect of disturbance is considerable. When the concentration of suspended solids is increased from 0.4 to 0.8 per cent, the volume of the sludge in a given unit of time is not twice as large but about 2.5 times. In another paper Townsend (3) states that "generally speaking, low temperatures appear at times to retard settling efficiency." He attributes this to retardation of biological activities. The relation between solids concentration and settling was also studied by Ridenour (4). He found that, in the type of plant studied (surface aeration), the rate of sludge concentration decreased in inverse proportion to the increase in suspended solids in the aerators. Brensky and Neave (5) found that the state of activation, character of sewage, temperature and dilution influenced the nature and character of the sludge. Dilution assisted the rate of settling. Clifford and Windrige (6) found that activated sludge settles more rapidly in wide than in narrow cylinders, which was assumed to be due to surface effects at the

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

walls. Increase in diameter beyond a certain point made little, if any, difference. "The relation between the shapes of the settlement curves with varying concentrations is unaffected by the diameter of the vessel." The effect of depth of vessel used (varying only 4.5 to 10.15 inches) on the percentage volume of the sludge was practically nil after several hours settling. It was found that an increase in concentration of the sludge produced more than a proportionate increase in the volume of settled sludge obtained in a given time. The studies were made with sludges diluted with tap water. Settling was greatly influenced by the condition of the sludge, e.g., "poor" or "good" sludge. Schroepfer (7) in discussing the factors affecting the efficiency of sewage sedimentation, states that viscosity is more important than specific gravity of the liquid. Based upon a study of the literature he is of the opinion that depth and ratio of length to depth exert an important influence upon the efficiency of sedimentation of sewage. Shallow tanks are preferable.

The results of studies reported in this paper deal with the effect of temperature, increased and reduced pressure, concentration of sludge, shape of containers, settling at various angles, depth of containers, prolonged aeration, mixing, and the effect of concentration of returned activated sludge mixed with fresh solids. The activated sludges used were obtained from both direct and mechanical aeration devices. Sludges produced at different plants as well as material obtained with different devices in the laboratory were used.

Effect of Temperature

Temperature effects presumably may differ, depending upon the condition and time when the effect is exerted. A warm period during the day when aeration is in progress, followed by a rapid cooling during the time when the sludge is settling, may produce a different effect than a sustained warm period during both aeration and settling as compared with a cold period for aeration and settling.

To determine whether or not a difference between the temperature of aeration and that of settling has any effect on the rate of settling, a series of experiments was conducted with activated sludge collected from the Madison-Chatham, N. J., sewage treatment plant. This plant employs direct aeration through porous tubes. Batches of sludges were aerated in small tanks by forcing air through submerged tubes as practiced at the plant. The air volume and rate was similar in each case and only sufficient to maintain the activated floc in suspension. The solids concentration was approximately 1000 p.p.m. Unless otherwise noted all settling experiments were made in one-liter cylinders and suspended solids determined by Gooch filters.

A. Settling at Different Temperatures Than Aeration.—The different sets were aerated at 9°, 20°, 36°, 40° and 49° C., and each set settled at 9°, 20°, 36°, 40° and 49° C. (total of 25 series). Those aerated at 20° C. and settled at different temperatures were repeated 3 times, whereas the others were repeated once.

The average results of the different sets for each temperature are shown in Fig. 1. The curves show rather striking similarity. Any

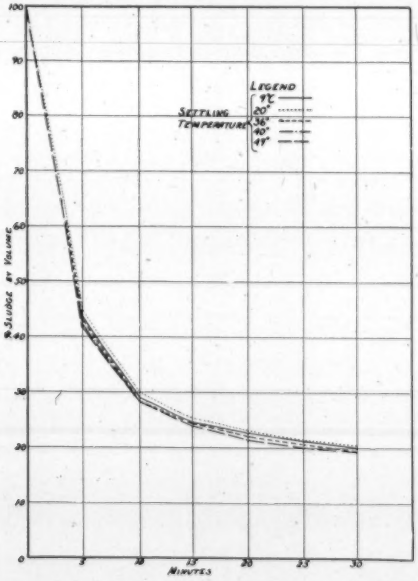


FIG. 1.—Rate of settling sludge at various temperatures.

small differences are well within the limits of experimental error. By averaging and disregarding the aeration temperatures it would appear that the settling temperature *per se* has no effect on the settling rate, but if differences in temperature set up convection currents, the rate of settling will be affected. Observations showed this particularly when the material was settling at the lowest temperature. At these lower temperatures the sludge in contact with the side walls of the container settled to a lower level than the portion further removed from the walls.

B. Aerating at Different Temperatures, Settling at Constant Temperature.—The different series were aerated for periods of 40 hours at 8°, 22°, 28°, 31°, 37° and 44° C. while settling took place at one (room) temperature. The average results of seven different sets of readings are shown in Fig. 2. The effect of aeration at different temperatures is clearly shown. The rate of settling of material aerated at 8° C. was considerably slower during the first 15 minutes than any of the others. This slower rate was not due to the rapid change in temperature from 8° to 22° C., which might cause unequal settling on account of stratifi-

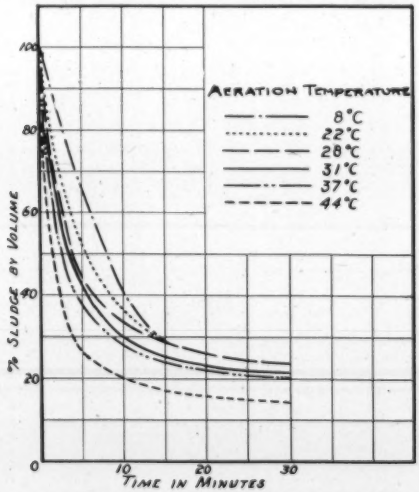


FIG. 2.—Effect of aeration temperature on rate of settling.

cation and cross-currents, because all samples were placed at the previously determined settling temperature for one hour and then inverted and settling tests made. The concentrations of sludge increased with the increase in settling temperature but this effect was not felt until the material was settled above 28° C.

C. Settling at the Same Temperature as Aeration.—The sludges were aerated at 8°, 22°, 37° and 43° C. and settled at the corresponding temperature. Four sets of tests were made for each temperature. The average results are shown in Fig. 3. It is apparent that there was a considerable difference in the rate of settling and the final volume of

sludge. With decreasing temperatures the sludge volume increased, although the differences became less with increasing time of settling. As might be expected the maximum variation occurred in the first five or ten minutes. Under ordinary conditions, with good sludge, the 5–10 minute intervals usually show the maximum settling rate, after this period there is a flattening of the curve. Taking the 30-minute settling volume and the volume of the sludge settled at 22° C. as 100, the in-

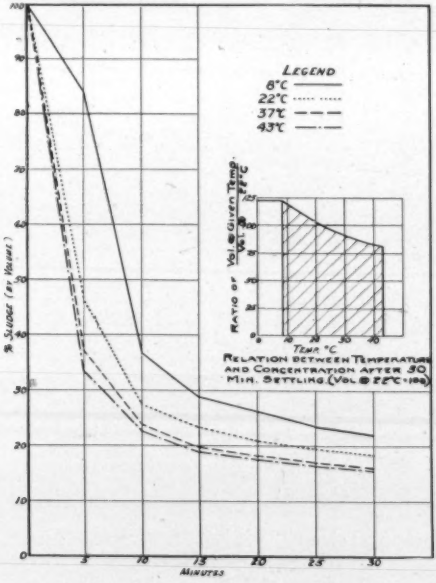


FIG. 3.—Rate of settling with aeration temperature the same as settling temperature.

creasing and decreasing percentage volume of sludge is graphically illustrated in the insert of Fig. 3. The volume of sludge aerated and settled at 10° C. appeared to be about 20 per cent greater, and about 10 per cent less at 30° C., than at 20° C.

It is apparent that the combined effect of aeration and settling temperature is of importance in settling and compacting of the sludge. A perusal of the curves in Fig. 3 shows that the slope of the curves did not vary directly with the temperature. It could be possible that

at some point between the temperatures of 8° and 22° C. the material would settle at a constant rate, at least for the first 10 minutes. Plotting the percentage sludge by volume at 5-minute intervals for the different temperatures (Fig. 4) it apears that none of the plots are straight lines, indicating that the rate of settling was not constant at any time between 0 and 30 minutes for any of the temperatures. These

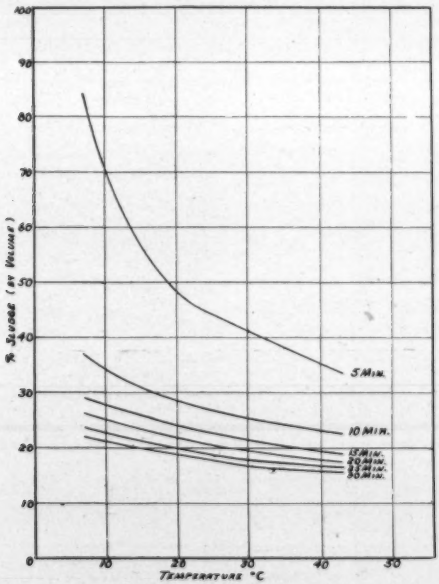


FIG. 4.—Relation between sludge volume and temperature after various periods of settling.

temperatures cover the usual range of sewage temperature in summer and winter. It should be remembered that ordinarily the sewage temperature varies from 10° C. to 24° C. so that the effect of temperature within these extremes would cause a difference of about 20 per cent in sludge volume. Practical experience has also shown that the floc does not settle as well if the temperature of the liquid and floc is lower than the average.

Effect of Pressure

An attempt was made to find experimentally whether or not settling under reduced pressure affects the rate of settling. Cylinders of 2 liter capacity with tightly fitting stoppers were used for the tests. Suspended from the stopper, inside the cylinder and above the liquid was a Tycos barometer. During each test the pressure was maintained within 0.1 inch of the figure recorded.

Several tests were made. The results obtained with a 3-inch difference in barometric pressure are given below as an illustration, the other data being similar in nature.

The per cent sludge settled at the two pressures during a 30-minute period was as follows:

Pressure Inches	5	10	15	20	25	30 minutes
27	67.5	49	43	38.5	35	33
30.5	71	51	43	39	35	33

This particular sludge had been subjected to treatment with air for three days. Another test, made with freshly collected sludge under the conditions noted above, showed almost the same settling characteristics. From the above figures it seems clear that even a sudden change of three inches in the barometric pressure did not affect the settling characteristics of activated sludge.

Effect of Concentration

A series of experiments was designed and conducted in an effort to determine the effect of (1) gradual increase in the suspended solids content and (2) gradual decrease in suspended solids content on settling. The experiments were conducted with activated sludge produced by mechanical and by compressed air aeration. The results from the compressed air experiment were obtained from 6 small tanks which contained the same sludge but in different concentrations.

Returned sludge from Madison-Chatham was used as seed in a 20-liter capacity aeration tank, using a Link-Belt straight-line aerator for agitation. The fill-and-draw principle was utilized, with 6 hours agitation of the sewage-return sludge mixture.

In this series of experiments, we are concerned only with the effect on settling of different concentrations of suspended solids and not with the degree of purification obtained.

The results obtained with solids concentration between the ranges of 800–1200, 1500–2000, 2500–3000 and 4000–5000 p.p.m. were averaged and the actual results obtained nearest to the averages were plotted in Fig. 5. The number of tests from which the suspended solids averages were calculated is shown for each curve. The curves indicate that the volume of settled sludge after ½ hour with similar concentrations was always less from the compressed air tanks than from mechanical aeration.

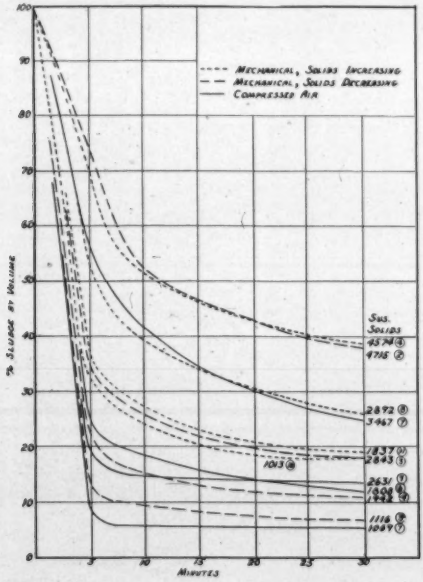


FIG. 5.—Effect of solids concentration on rate of settling.

However, when all results are averaged the differences are very small. Although the volume of sludge increased with the increase in weight of solids, the increase in volume was not directly proportional to the increase in weight. This is graphically shown in Fig. 6, where the calculated volume is represented by the solid lines, and the actually found volumes after ½ hour settling for the different concentrations are indicated by the dotted lines. The assumed volume was calculated by multiplying the volume at the lowest solids concentration by the increase

in weight of solids. The differences become larger with the increase in density of sludge. A glance at the curves of Fig. 5 shows that the sharp break in the settling curves of the lower sludge concentrations becomes less and less as the solids concentration increases. The sharp break in the curves is usually taken as an indication of a rapidly settling sludge. In more concentrated sludges it is more a measure of the crowding of particles, interfering with each other in their progress downward.

It should be remembered that the settling tests were made in one-liter cylinders. When cylinders are used of smaller diameter the differ-

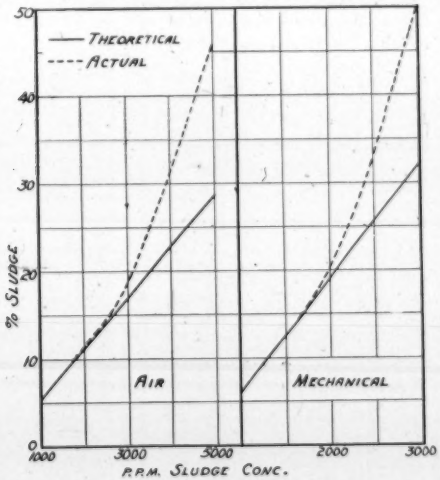


FIG. 6.—Theoretical and actual volumes of sludge after thirty minutes of settling.

ences are even more emphatic. In reality we deal in such cases with differences in settling and compacting. Sludge with increasing concentrations occupies more and more space in a given time on account of the increased time required for compacting. Settling time must therefore be increased, both with "good" and "poor" sludge. When the sludge concentration is too great in reference to the settling capacity, a condition often erroneously called "bulking" exists, due to lack of space for sludge movement. Such a voluminous sludge does not necessarily give rise to poorly oxidized effluent, but the sludge can not be held in the sedimentation tank and a part may pass over the weirs.

The results plotted in Fig. 5 show also that when the solids were increasing, a larger sludge volume was obtained for a given weight than when the solids were decreasing. This difference is due to another factor, namely the condition of the sludge. Similar results were shown by Voelker (8). During the period when solids were increasing the purification power of the sludge was less than during the period of decreasing suspended solids. Inferior sludge results in a lag in settling.

Effect of Shape of Containers

Activated sludge was settled in different shaped containers at room temperatures, in order to learn whether or not the shape of the settling container affected settleability. Madison-Chatham sludge, aerated for four hours, was used in this series.

Different volumes of sludge were placed in containers of the following dimensions:

	Height Inches	Width Inches	Volume c.c.
Jar	6¼	4⅞	2000
Straight cylinder	13¼	2⅜	1000
Straight tube	52½	⅝	300
Funnel	5⅞	6¾ (top) 1¼ (bottom)	1000

The results obtained were averaged and are presented in Fig. 7. The settling curves are plotted from values calculated by dividing the total liquid height by the volume of sludge at 5-minute intervals and expressed in per cent.

It will be seen from Fig. 7 that (1) when the concentration of sludge increases the volume of sludge increases (Section *A*); (2) except in the case of the lowest concentration, the greater the depth of the liquid the slower the rate of settling; (3) except in the lowest concentration, the rate of settling was fastest in the funnel; (4) excluding the funnel tests, the greater the surface area the more rapid was the settling rate (Section *C*); (5) for a given sludge concentration the shape of the container made very little difference in the per cent volume occupied after 30 minutes settling (Section *B*).

The straining action of floc, or its ability to adsorb finely-divided particles, and thus cause these particles to settle with it, is well known. The greater the distance the floc travels the more material, within limits, it carries with it. With a greater height of liquid column a given weight of floc would be expected to adsorb more of the finely-divided

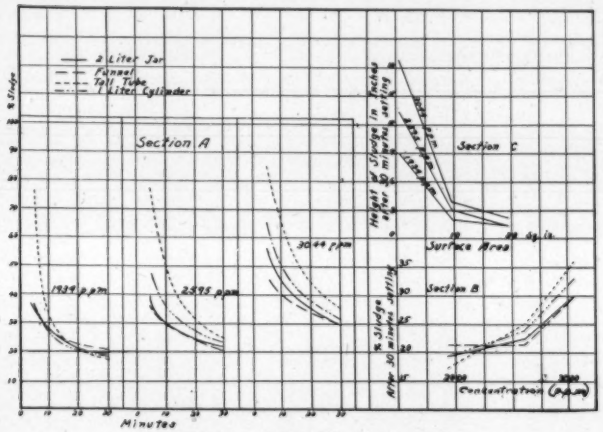


FIG. 7.—Effect of shape of settling container.

suspended solids. This would account for the lower turbidities found in the liquid from the tallest container.

The height of the column affects the concentration of the settled sludge. This is shown in Fig. 8, where the volume in cubic inches after 30

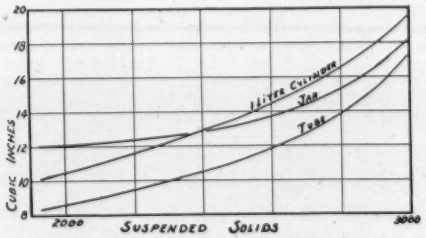


FIG. 8.—Relation between suspended solids and volume of settled sludge, in containers of various heights.

minutes settling is plotted against the suspended solids of the mixture in parts per million. The tallest container (tube) showed the greatest compaction. If the height of the liquid column alone was responsible for the compaction it would be expected that the amount of sludge would vary directly with the depth of the liquid. However, the effect of the friction of particles, the ratio between floc size and settling con-

tainer square area upon minute currents caused by floc movement, and the effect of convection currents must be taken into consideration. Just what value the various individual factors have is difficult to determine experimentally, but the aggregate result may be appreciable.

Effect of Depth on Settling

In order to study the effect of depth on the settling rate and compacting of activated sludge, three cylinders of the same diameter (2½ inches) but of different lengths were used and operated at room temperature. The effective depth of the containers was respectively 5 ft.

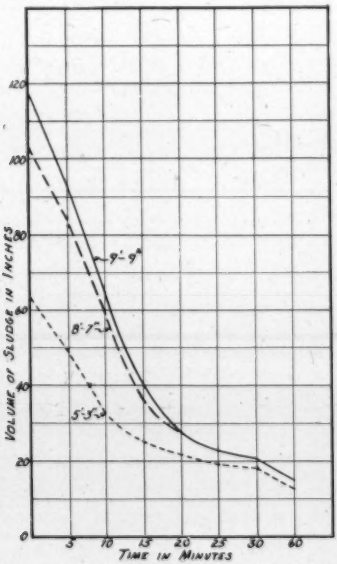


Fig. 9.—Effect of depth on settling. Volume of sludge constant.

3 inches, 8 ft. 7 inches and 9 ft. 9 inches. Well-aerated activated sludge from the Tenafly, N. J., plant was added to each container to a height of 5 ft. 3 inches and supernatant liquid added to fill the two taller containers. After thorough mixing, with air supplied from the bottom of the containers, the sludges were allowed to settle and readings taken every 5 minutes. Fig. 9 shows graphically the volume of sludge settled

at each 5-minute interval for 30 minutes and a shortened section for the second 30-minute settling.

All cylinders had the same amount of sludge. After 30 and 60 minutes settling the volumes occupied by sludge were nearly identical.

In another set of experiments quantities of the same sludge were placed in the containers in proportion to the height of the container. The sludge was mixed by air. The readings taken at 5-minute intervals are shown graphically in Fig. 10. The sludge volumes occupied after

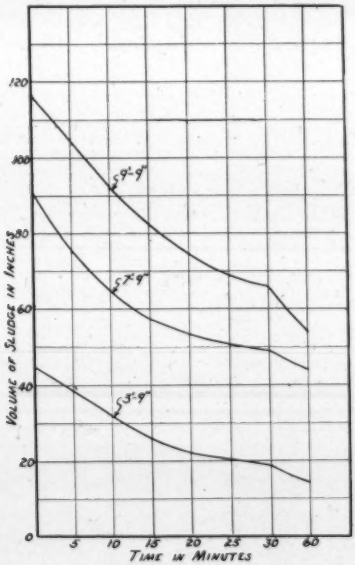


FIG. 10.—Effect of depth on settling. Volume of sludge in proportion to height of column.

30 and 60 minutes in the cylinder 118 in. high were more than 3 times the volumes occupied by the sludge in the cylinder 45 in. high, or in other words, that the degree of compacting in the taller cylinder was less. This is more clearly shown in Fig. 11, where the actual volumes of sludge in inches are shown for different depths after ½, 1, and 3 hrs. settling as well as the "theoretical" volumes, which are computed as the volume of sludge present in the shallow container multiplied by the pro-

portional increase in height (with proportional quantities of sludge). It is interesting to note that the relative volume required increases with the depth. This holds for the 3-hour quiescent period as well as for the ½-hour period, but the compacting tendency is in such direction that eventually the relative sludge volumes may be identical.

The results of these experiments indicate that the time required for settling and compacting is longer in deep vessels than shallow ones, provided the containers have the same surface area. The rate of compact-

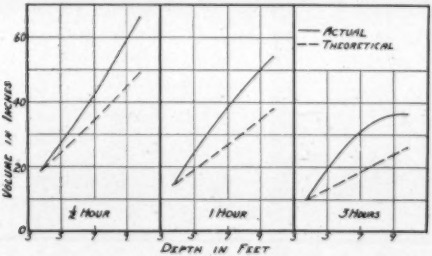


FIG. 11.—Effect of depth of settling. Theoretical and actual volumes of sludge.

ing is materially affected by the crowding of particles, so that the sludge does not settle or compact to a degree comparable with its concentration.

Of the two physical factors, area and depth, that affect settling and compacting in containers of equal diameters or equal depths, it appears that increases in depth do not increase the rate of settling nor the rate of compacting of activated sludge. Since area affects the ratio of settling (as shown elsewhere in this paper), a shallow tank of the same capacity as a deep tank would produce better results. However, this conclusion holds only for comparatively short times of settling and compacting (½ hr. or less). When the period of settling is materially increased the compacting is greater in the deeper vessels. This is illustrated by the following figures taken from a settling experiment with concentrated sludge and proportionate sludge volumes:

Depth	Per Cent Sludge by Volume		
	1 hr.	3 hrs.	19 hrs.
3′–9″	32	22	16
7′–9″	40	31	14
9′–9″	46	37	12

The differences on a unit basis after 19 hours settling appear comparatively small (25 per cent less in deeper vessel). In ordinary operation such long times are not used, but for concentrating waste activated sludge a deep tank appears to have rather an advantage over shallow tanks.

From the laboratory experiments it is clear that the first 10 minutes of quiescent settling are of great importance and if during this period settling is impaired by crowding of particles, the results would be poorer than could be expected.

Settling at Various Angles

In this series of tests four 1-liter cylinders were so arranged that the settling took place at the same temperature. The cylinders were placed at 90° (vertical) 75°, 60° and 45° angles. Three sets of tests were made, using various concentrations of solids. The sludge used was sampled after four hours reaeration, and was in good condition.

Pearse (1), in the report of experimental work at Chicago and Packingtown stated that "the same degree of concentration was obtained in 20 minutes in the 60 degree cylinders as was obtained in one hour in the vertical cylinders." The settling tests were made in 100 c.c. cylinders. The concentration of solids was not stated. A maximum settling to 20 per cent of the original volume in 60 minutes was obtained with a mixture of sewage and sludge, settled at an angle of 51°. Large-scale tests with inclined-baffle settling tanks showed considerable advantage in rapidity of settling, as compared with vertical-type settling tanks, but doubt was expressed concerning the practicability of inclined-baffle tanks.

The results obtained in our experiments were averaged and are graphically shown in Fig. 12. The curves in the upper section of the figure show settling characteristics of three different sludge concentrations placed at angles of 90°, 75°, 60° and 45° referred to the base. In each case the greater the angle from vertical, down to 45°, the less volume was occupied by the sludge after 30 minutes quiescent settling. The minimum volume in each case was occupied by the sludge settled at 45° and the maximum by the sludge settled at 90° to the horizontal. The greater the concentration of solids the more pronounced was the difference in volume between that settled at 90° and 45°. When the per cent concentration of sludge obtained by vertical settling is taken as a base figure, and the time required for the same sludge settling at different angles to reach the same volume of sludge is used as a variant, settling is shown to be better when carried on at any degree of angle rather than vertically. For example, the sludge containing 3200 p.p.m.

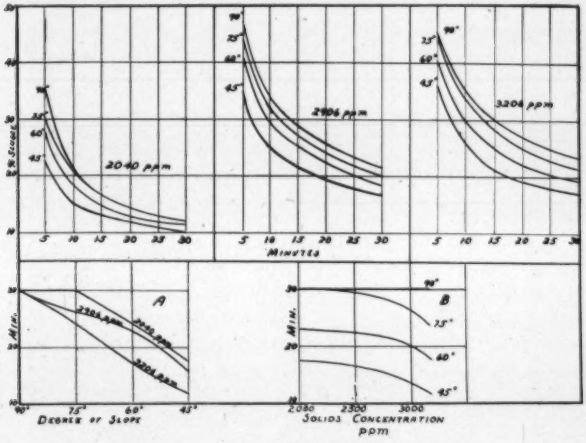


FIG. 12.—Relation between slope of container and rate of settling.

suspended solids settled to 24 per cent of the volume in 30 minutes in the vertical cylinder. This same volume was reached by the sludge settled at 75° in 24 minutes, at 60° in 17.5 and at 45° in 12 minutes. The effects of the different slopes are graphically shown in section *A* and *B* of Fig. 12.

Effect of Aeration Time

The effect of so-called "over aeration" on settling has been held to be responsible in some cases for poor settling. A quantity of activated sludge was aerated continuously for a period of nineteen days. Settling tests were made daily and readings made in the ordinary manner. The results obtained for the 10, 20 and 30-minute periods are graphically shown in Fig. 13. There appears to be a gradual decrease in the volume of sludge settled with increase in time. This decrease is partially due to the decrease in suspended solids on account of the continuous aeration, and partially to greater compactness of the floc. It does not appear that at any time the settling characteristics were impaired. The physical appearance of the sludge did not change much during the period of aeration, except that it took on a lighter shade of brown. The supernatant liquid became increasingly yellow and brownish probably due to humic acids in solution. With a less abundant air supply the char-

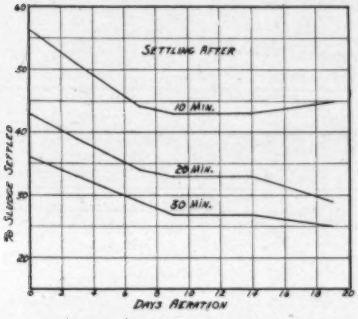


FIG. 13.—Effect of prolonged aeration on sludge settling.

acter of the floc changes rapidly, becomes finely divided and may be less amenable to settling.

EFFECT OF STIRRING

A large number of experiments were made dealing with the effect on settling and compacting of stirring or mixing of returned activated sludge. Three methods of stirring were used (*a*) gentle mixing by stirring the mass once slowly by means of a plunger, (*b*) moderate shaking by stirring the mass rapidly 3 times and (*c*) violent shaking by placing the material for 2 minutes in a shaking machine. The density of the sludges used varied from 0.136 to 0.32 per cent. As might be expected, the dilute sludge settled during the first two hours to a greater degree than the more concentrated sludge. After the sludge had been treated as indicated above, it was allowed to compact for about 95 hours. The average results of several trials are shown in Fig. 14. In 95 hours the sludge had compacted to about 40 per cent of its original volume. Stirring affected the results only to a very slight degree. It would appear, therefore, that it matters little whether the settled sludge is conveyed by gravity or by pumping, to be concentrated afterwards. Some of the individual results show that the time required for compacting varied with the density of the sludge. The most dilute returned sludge reached a volume of 40 per cent in about 75 hours, while the most concentrated compacted to the same percentage volume in about 110 hours.

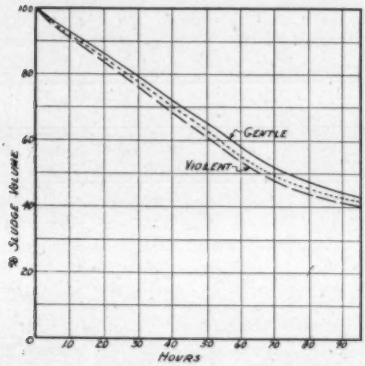


FIG. 14.—Effect of agitation of sludge on settling.

EFFECT OF STALENESS OF SLUDGE

The effect of staleness on settling is graphically illustrated in Fig. 15. Activated sludge with sewage added had been aerated for 40 hours to insure good settling. After the settling test was made the sludge was left standing in the cylinder for 24 hours at room temperature, thoroughly mixed with a plunger and resettled. This procedure was followed consecutively for five days. The diagrams show the percentages sludge settled in 5, 15 and 30 minutes, together with the position of the sludge and the physical conditions of the material.

The material gradually became septic and began to evolve considerable quantities of gas. Most profuse gasification occurred on the second day, when the color of the liquid began to change. The blackness of the material increased gradually, which is indicated by the manner of shading. It is apparent that the gases formed retarded settling and compacting and caused the sludge to rise.

On the third day gasification decreased and the sludge particles appeared to be more granular. The sludge layer became more and more indistinct. With increasing septicity (4th and 5th day) the volumes of sludge settled after 30 minutes were but slightly greater than at the beginning of the experiment. However, a portion of the very finely divided material was undoubtedly present in the supernatant. In general, it might be concluded that with increasing septicity the sludge settles and compacts at a slower rate.

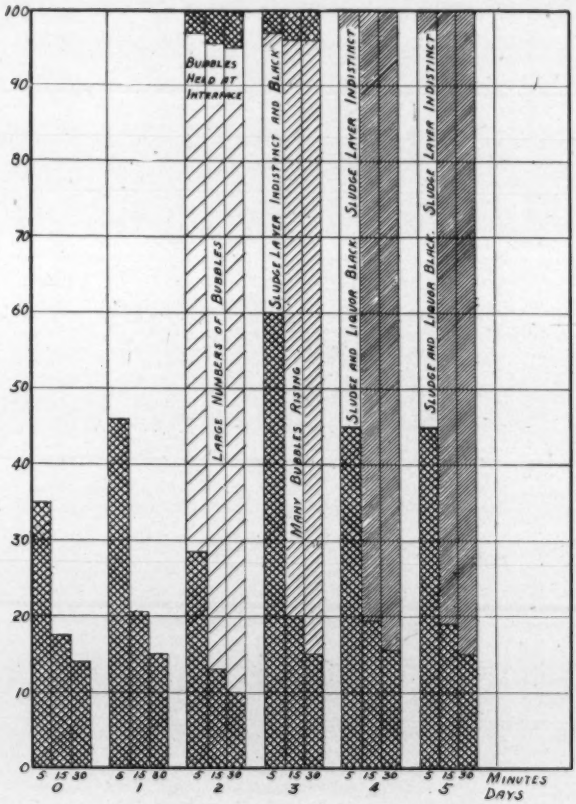


FIG. 15. Effect of age of sludge on settling.

EFFECT OF FRESH SOLIDS

An attempt was made to obtain some information on the influence of fresh solids, added to return activated sludge, on the degree of compacting. After a number of preliminary tests, experiments were made in a series of one-liter cylinders, using activated sludge with 0.20 per cent and fresh solids of 6.76 per cent total solids content. Of the several series of experiments conducted, an example (averages of 3 sets) is

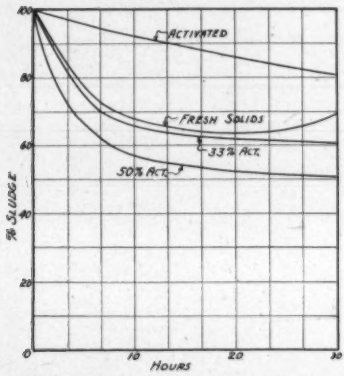


FIG. 16.—Effect of fresh solids on settling of activated sludge.

given in Fig. 16. The sludges used were: returned activated sludge alone, activated plus 66 and 50 per cent fresh solids and fresh solids alone.

During the first 6 to 7 hours the mixtures compacted more rapidly than the activated sludge alone. After 30 hours the 50:50 mixtures (by volume) had compacted 50 per cent, while the activated sludge had compacted only 19 per cent. It required from 75 to 80 hours before compacting of the activated sludge equalled that of the mixtures. The fresh solids had separated and most of the material was floating on top, while activated alone and the mixtures remained nearly completely at the bottom. After 30 hours all material began to float. The time required before floating varied with the temperature. With higher temperatures the materials began to float in a shorter time. The rate of compacting is not constant for all sludges. It varies with sludges produced at different places (character of sewage?), also with concentration and condition of the sludge. As an example of the differences the following figures are illustrative:

Place	% Solids in Sludge			% Compacted		Condition of Act. Sludge
	Act.	Fresh	Mixed	Act.	50 : 50 Mix.	
Mad.-Chatham.....	0.30	6.50	3.40	69	74	Good
"	0.31	2.64	1.48	29	45	Poor
Morristown.....	0.32	5.78	3.05	62	67	Good

Poor activated sludge, although of approximately the same concentration, compacted far less than sludge in good condition. When mixed with fresh solids the poor sludge affected the compacting of the mixture.

The different mixtures were also stirred, gently, moderately and violently. The results of tests with two sets of mixtures of activated sludge and fresh solids are shown in Fig. 17. The sludge volume after

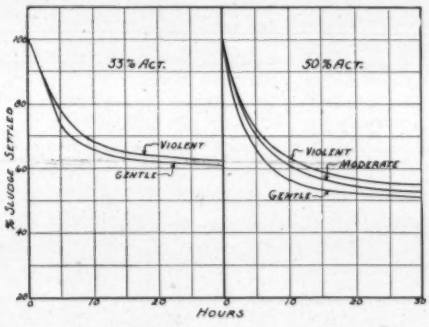


Fig. 17.—Effect of stirring on compacting of mixed sludges.

30 hours settling of returned activated sludge, mixed with $\frac{2}{3}$ fresh solids, was almost constant no matter how the mixtures were treated. It appears that the manner of mixing of fresh solids with activated sludge does not have any pronounced effect upon compaction.

It was of interest that with increasing degrees of stirring the liquid of the mixtures became clearer on standing and that the mixtures of activated plus fresh solids produced a much clearer supernatant than that of the fresh solids alone.

Discussion

There are several possible explanations for the difference in settling rates under different temperature conditions. The factors involved may possibly be divided into two groups, biochemical and physical.

Biochemical.—Biochemical factors affect settling through changes in the rate of activities of the flora and fauna. With increasing temperatures the rate of activities increases, with subsequent increases in the rate of "clotting" or coagulation power. The result is in general an increase in size and density of the floc. An increase in the size of floc, or rather an increase in the rate of coagulation power, does not necessarily mean good settling. This holds especially at the higher tempera-

tures, when the size of the floc may increase to such an extent that the settling rate is lowered.

When the sludge is aerated at a higher temperature than that at which it subsequently settles the effect is less than when the sludge is aerated at a lower temperature than at which it is settled.

Physical.—The results of our studies indicate that aeration temperature is relatively more important than settling temperature on the volume of sludge produced after settling 30 and 60 minutes. Aeration temperature affects also the rate of settling to a greater extent than settling temperature. This is shown by the condensed results for aeration at 9° and 49° C. and settling at different temperatures given in Table I. For example, with a constant aeration temperature at 9° C.

TABLE I.—*Relative Importance of Aeration and Settling Temperatures (Expressed in Per Cent Settled in Given Time)*

Settled ° C.....	9		20		36		40		49	
Aerated ° C.....	9	49	9	49	9	49	9	49	9	49
Min.										
5	67	27	68	26	65	26	62	27	67	26
15	27	18	28	18	27	17	27	17	27	17
30	20	16	21	15	21	14	21	13	21	13
60	17	14	16	12	16	11	18	11	18	11

Note: Original sludge concentration 1130 p.p.m.

there is practically no difference in the volume of sludge settled at different temperatures, but with a constant aeration temperature of 49° C. there is a gradual effect with the increase in settling temperature. This holds for both 30 and 60 minutes settling. On the other hand, the sludge volume produced at all settling temperatures is materially greater with low than with high aeration temperature. Results show that with originally denser sludge, the differences are somewhat less, but the same tendency prevails.

Rather complete notes were kept during the experiments and it is of interest to compare the condensed notes dealing with the two sets of experiments as given in Table II.

There are two conditions of interest, namely, (1) gas production and subsequent floating and (2) manner of settling of sludge particles. If it be assumed that at higher temperatures of aeration the increased activities of the organisms would produce more gas bubbles, the visual evidence is contrary. The time required for the appearance of gas bubbles in the mixtures aerated at low temperature was considerably

TABLE II.—*Observations on Behavior of Sludges*

Time, Min.	Aeration Temp. 9° C.	Aeration Temp. 49° C.
5	All samples poor settling; considerable floc (large particles) throughout liquid.	9° and 20° some floc diffused throughout liquid, 36°, 40°, 49° liquid clearer only small floc-suspension.
15	Sludge line marked, liquid clear.	9° and 20° sludge settling in mounds; difference in height between top of mound (center) and bottom of mound 30–50 c.c.
30	9° and 20°, liquid more transparent than at higher temp. Floc at higher temp. larger in size. Sludge line marked.	Liquid transparent, sludge in mounds.
60	Numerous gas bubbles in 49° and 40°, small quantities in 36°, few in 20°, sludge rising in 49°.	No gas apparent in any sample.
75	Gas bubbles very numerous in 36°, 40°, 49°.	No gas apparent.
90	49°, all sludge at top.	Very few gas bubbles in 36°, 40°, 49°.
100	40° break in sludge column, 20° few gas bubbles.	No change.
200	36°, 40°, 49° sludge at top.	36° sludge diffused throughout cylinder, 40° sludge rising, 49° few gas bubbles when sludge is gently moved.
300	9° no gas bubbles, 9°, 20° sludge at bottom.	9° no gas bubbles, sludge at bottom. 20° few gas bubbles, sludge at bottom.
24 hrs.	9°, 20° sludge at bottom, 9° no apparent gas bubbles.	9°, 20° sludge at bottom, 9° no apparent gas bubbles, 20° few bubbles on shaking.

shorter than in the mixtures aerated at higher temperatures. The sludge also started to float sooner in the mixtures aerated at low temperatures. Gas bubbles appeared sooner in those mixtures aerated at high

temperatures and kept at the same temperatures than those aerated at high and settled at lower temperatures. It is clear, therefore, that both biological and physical factors were involved.

Biological activities accelerated gas production and the expansion of the gas causes the solids to float. This floating or rising of sludge does not necessarily mean that the particles are buoyed up individually. In cases where the floc was large and rather compact the whole blanket would rise within a short time, moving through the liquid with hardly any disturbance, or leaving detached floc in its wake. In other experiments, with small tanks, the settled sludge would curl at the edges and the whole mass would be lifted. It is evident that the gases are held, at lower temperatures, both in solution and as bubbles. More gas dissolves at lower temperatures and the viscosity of the liquid retards expansion. At higher temperatures the bubbles escape more easily. At lower settling and compacting temperatures the gas is produced at a slower rate, held longer and more tenaciously by the floc and thus accelerates floating. Floating of the sludge blanket is therefore not affected by the aeration temperature but by the settling temperature. More detailed accounts and description of this sludge movement will be given in another paper dealing with this phenomenon.

There are several possible explanations for the differences in settling rates under various temperature conditions.

a. Change in viscosity of the liquid.
b. Change in surface tension.
c. Change in internal tension due to dissolved gases.
d. Effects of currents.
e. Ability of material to flocculate.

a. A rise in temperature decreases the viscosity of the liquid. Between the limits of 8° C. and 43° C. the viscosity decreases about 5 per cent. Such a decrease should be felt in the settling. If viscosity plays an important rôle, it would seem to exert itself mostly at the higher temperatures (above 28° C.) which are out of the usual range in practice, but at lower settling temperatures it is a factor to be reckoned with.

b. If the surface tension changes were wholly responsible for the differences in settling rates, the averaged results (Fig. 1) would probably show the effect. It is concluded that surface tension is of relatively small influence.

c. The presence of gases in solution should exert considerable effect. The gases consist principally of oxygen brought into solution by the aeration, and of CO_2 produced as an end-product by the biological activities. If the tension caused by these gases were an important factor, a noticeable difference should be caused by changes in partial pressure.

No great differences in settling were found when the sludge was settled at slightly reduced or increased atmospheric pressures. Experiments showed, however, that the settling rate was retarded during application of a greatly reduced pressure. However, after applying the reduced pressure for one hour, followed by mixing, it was found that the settling rate very closely approximated that of a similar sludge settled quiescently for 60 minutes, followed by mixing.

Comparing settling rates in sealed and open containers, and again after the sealed container was opened, the differences were very small. The results given in Table III illustrate this point. It is apparent

TABLE III.—*Comparison Between Sealed and Open Container and Resettled Sludge After Opening of Container*

Time, Min.	Per Cent Sludge Settled		Time, Min.	Per Cent Sludge Settled	
	Sealed	Open		Unsealed	Open
5	62	61	5	61.5	62
10	50	48	10	49	49
15	44	41	15	42	42
20	40	37	20	37	38
25	37.5	34	25	34	34.5
30	34	32.5	30	31	32

that if part of the dissolved gases are removed by reducing the pressure, or by inverting the mixture, so that gas is released from the closed vessel, the settling is practically unaffected.

Although the differences in settling rates are small, the results of repeated tests show that a sudden change in pressure exerts some influence. When pressure is reduced considerably below a prevailing high atmospheric pressure (from 30.35 to 27 inches) some of the floc breaks apart and may leave finely divided particles in the supernatant. It happens with considerably less difference in pressure when the prevailing atmospheric pressure is low, for instance when reduced from 29.7 to 27 inches.

d. There is a possibility that two types of currents occur during settling: (1) convection currents caused by differences in temperature in the settling material and (2) displacement currents. The results given in Fig. 1 were obtained by settling at different temperatures than aeration and then averaged. Under these conditions any noticeable effect of either the settling or aeration temperature is counterbalanced. When the sludges were aerated at different temperatures than settling (Fig. 2) settling and compacting were more rapid at higher tempera-

tures, and when settling was done at the same temperature as aeration similar results were obtained. If currents caused by changes in temperature of the settling mixtures are important in affecting the rate of settling, it might be assumed that the greater the temperature difference the greater the effect. This is borne out by the observations that if settling is carried on under conditions where local changes of temperature take place, such as settling in the warm sunlight or near a heated surface, where the liquid is heated unequally, the rate of settling is retarded by the rising flow of liquid on the heated side.

The effect of displacement currents would be the same for all mixtures with the same concentration, while the effect would presumably be greatest in the mixtures with the greatest settling rates. As a whole, therefore, convection and displacement currents would be most detrimental in the mixtures settling at the greatest temperature differences.

e. In considering the ability of the material to floc, several factors play a rôle. They can be divided conveniently into: (1) biological, (2) chemical and (3) physical. No major biological or chemical changes were made, except as influenced by physical factors such as temperature, concentration of sludge and prolonged aeration. It is not the purpose of this paper to discuss the biochemical changes which take place, but only the resulting effects. Some of the factors mentioned, such as temperature, are well known to affect the rate of coagulation. Ordinarily better coagulation and flocculation are obtained at higher temperatures, but good flocculation does not necessarily mean good settling. Nevertheless, it is possible that the relative increased size of the particles formed at higher temperatures affected the speed of settling, as indicated by the sharp change in the slope of the curves at higher temperatures. Prolonged aeration did not affect greatly the settling rates from day to day, but there was a continuous gradual change as indicated for the first four days (Fig. 18), so that after this prolonged aeration the settling rate of the same sludge was greater. Since no fresh sewage was added to the mixture, there was some loss of material due to oxidation, but prolonged aeration did not produce more voluminous sludge nor a slower settling rate. Similar experiments were repeated over shorter aeration periods than 24 hours with similar, but less pronounced results. With increased concentration of sludge the proportional increase in volume was greater than the increase in concentration.

No specific attempt has been made in this paper to discuss the difference between settling and compacting, but it is clear that the two phenomena should be separated. The question of where settling stops and compacting begins may be indicated by a sharp break in the settling curves. This break is noticeable in the settling curves of most activated sludges, which are in good condition. As a rule, when the character

of the sludge is poor the break does not occur so sharply. When trade wastes are present in the sewage the sludge settling characteristics may change in good as well as in poor sludge. If it be assumed that compacting begins when the break in the settling curve occurs, the rate of compacting thereafter is influenced chiefly by time.

In actual operation the rate of compacting becomes important when the sludge must be resettled for final disposal. The question of resettling activated sludge was investigated rather extensively. Results of our tests show that concentration, if any, was very small. Since the time factor is very important in compacting, the question of subsequent condensing of resettled activated sludge is closely linked with such fac-

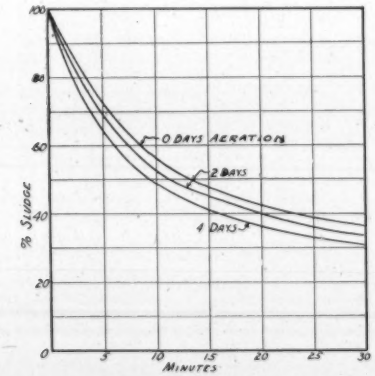


FIG. 18.—Rate of settling of activated sludge, subjected to prolonged aeration without introduction of sewage.

tors as initial concentration, temperature and staleness of the sludge. As has been shown, temperature ranges between 8° and 20° C. do not materially affect compacting. Settled sludges with concentrations of 1.5 to 2.5 per cent solids held at these temperatures reached the same concentration in 80 to 95 hours. Staleness may lead to floating, but apparently has little influence on compacting. Although the material floats in mass, compacting continues.

The interesting results obtained with different quantities of fresh solids and activated sludge are worth consideration. Mixture of activated and fresh solids between the limits of $\frac{1}{3}$ to $\frac{2}{3}$ fresh solids (by volume) added to activated sludge settled better and compacted to a greater

extent during the first 3 days than either activated or fresh solids alone. Thereafter, compacting reached the same degree in all combinations tried. Mixtures of about 1 volume of fresh solids and about 1 volume of activated sludge compacted most rapidly. It is also of interest that such mixtures have less tendency to float than fresh solids. Apparently the clotting power of the activated sludge exerts sufficient influence to coagulate a part of the fresh solids, allowing the mixture to settle and compact more readily. However, when the mass becomes very septic the initial differences disappear. The rate of compacting of mixed sludges should not be confused with the density of mixed sludges in digestion tanks. It is well known that mixtures of activated sludge and fresh solids as a rule do not produce the same density of digested sludge as fresh solids alone.

Summary

Experiments dealing with the effect of a number of factors influencing the rate of settling and subsequent compacting of activated sludge indicate that some factors are beneficial, others detrimental and some have no practical effect. With increasing aeration temperature the rate of settling increases. With increasing settling temperature the rate of settling decreases. A differentiation between settling and compacting is made. Pressure has little effect on settling, while suction appears to increase the rate of settling. With increasing solids concentration rates of settling and compacting are retarded. The greater the depth of the liquid the slower the rate of settling; the greater the surface area the faster the rate of settling and the greater the compacting; the latter irrespective of the sludge concentration. With a given sludge the shape of the container makes little difference in the per cent volume occupied after 30 minutes settling. Although the rate of settling in deep vessels is retarded, compacting in deep vessels may overbalance the advantage of rapid settling in shallow vessels. The greater the angle from vertical the less volume is occupied by the sludge after 30 minutes settling. Continuous aeration of good activated floc showed a gradual decrease in volume of sludge settled. Repeated stirring and mixing was of little practical importance on subsequent settling and compacting. With increasing septicity the sludge settles and compacts at a slower rate. Fresh solids added to activated sludge cause the mixtures to settle and compact at a more rapid rate than activated sludge alone. The quality of activated sludge (ability to clarify and oxidize) affects the settling properties, even when mixed with fresh solids. Violent stirring of the mixtures affects the movement of the solids.

References

1. Pearse, Report on Industrial Wastes from Stockyards and Packington, Chicago. II, 137 (1921).
2. Townsend, *Proc. Amer. Soc. Mun. Impr.*, **34**, 228 (1928).
3. Townsend, *Mun. San.*, **3**, 18 (1932).
4. Ridenour, *This Journal*, **6**, 36 (1934).
5. Brensky and Neave, *Ill. State Water Surv. Bull.*, **18**, 58 (1923).
6. Clifford and Windridge, *Proc. Inst. Sew. Purif.*, 115 (1932).
7. Schroepfer, *This Journal*, **5**, 209 (1933).
8. Voelker, *This Journal*, **6**, 947 (1933).

BACTERIAL NUMBERS IN ACTIVATED SLUDGE MIXTURES *

By H. Heukelekian

Associate, Dept. Water & Sewage Research, New Jersey Expt. Station

It would be of great value for the understanding and control of the activated sludge process if some correlation could be found between the bacterial flora of the sludge and the purification obtained by the process. It is to be expected that the types of bacteria change, as the sewage is aerated, from those normally present in the sewage to those that can be called the activated sludge flora proper. If there is such a change, it follows that the flora in sludges of different characters and purifying efficiencies must be different. So far, however, an accurate enumeration of the different types of bacteria under various conditions of oxidation has not been undertaken. We have therefore carried on some studies and have obtained results showing gross bacterial numbers in activated sludge mixtures subjected to various experimental conditions. This paper will deal with certain differences in the character and performance of activated sludge from the standpoint of the numbers of bacteria.

I. *Effect on Bacterial Numbers of Additions of $CuCl_2$ to Activated Sludge Mixtures.*—As a part of a major study of the effect of certain catalysts on the activated sludge process, bacterial numbers were determined on variously treated activated sludges. The procedure was to aerate the sludge mixture during a portion of the day (4 to 6 hrs.) and to allow it to rest for the remainder of the day. On the following day sufficient volume of the mixture was withdrawn to give the desired sludge concentration with the daily charge of sewage. The catalyst, in this study $CuCl_2$, was added daily in portions varying from 0 to 8 p.p.m. of $CuCl_2$ as Cu. The analyses, among other determinations, included daily determination of the B.O.D. of the raw sewage added and of the supernatant liquor after 30 minutes sedimentation; a daily check on the suspended solids content of the aeration tank contents, raw sewage and of the supernatant after 30 minutes sedimentation. Once a week total plate counts were determined on 100 c.c. portions of the mixtures settled to 20 c.c. The results of five such weekly counts are given in Table I. It will be seen that the bacterial numbers per c.c. varied considerably from week to week. Even when the results are corrected for variations in suspended solids contents these variations are not entirely obliterated. It will be seen, however, that the bacterial numbers were generally higher

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water & Sewage Research.

TABLE I.—*Weekly Results on Bacteria and B.O.D. Reductions of Sludge Mixtures Aerated With Different Amounts of $CuCl_2$*

	$CuCl_2$ as Cu p.p.m.	Suspended Solids in Mixtures (p.p.m.)						Bacteria in Millions per C.C. (1)					
		Oct. 24	Nov. 3	Nov. 10	Nov. 17	Dec. 1	Ave.	Oct. 24	Nov. 3	Nov. 10	Nov. 17	Dec. 1	Ave.
1	0	1410	2385	1410	1440	825	1495	67.0	94.0	39.0	50.5	170.0	86.0
2	0.5	1390	2330	1375	1395	860	1470	18.5	17.5	78.5	65.0	97.5	55.4
3	1.0	1580	2465	1250	1300	815	1480	29.0	29.0	48.0	124.0	205.0	87.0
4	2.0	1530	2125	1290	1440	875	1450	135.0	27.5	52.0	10.10	27.0	68.5
5	4.0	1360	2435	1400	1430	910	1505	250.0	38.5	83.0	90.0	157.0	123.7
6	8.0	1635	2425	1630	1410	980	1615	300.0	120.0	200.0	300.0	455.0	281.0

TABLE I (*Continued*)

	$CuCl_2$ as Cu p.p.m.	Bacteria in Millions per Mg. Susp. Solids						B.O.D. Reduction in Per Cent					
		Oct. 24	Nov. 3	Nov. 10	Nov. 17	Dec. 1	Ave.	Oct. 24	Nov. 3	Nov. 10	Nov. 17	Dec. 1	Ave.
1	0	9.5	7.8	5.5	8.4	41.2	14.5	89.0	92.5	94.0	92.8	75.0	88.6
2	0.5	2.6	1.5	11.4	9.3	22.6	9.5	87.0	90.0	91.0	92.0	82.0	88.4
3	1.0	3.6	2.3	7.7	19.1	50.4	16.6	87.0	90.0	94.0	92.0	87.5	90.1
4	2.0	17.6	2.6	8.1	14.0	6.1	9.7	86.0	91.5	93.0	88.0	87.5	89.2
5	4.0	36.7	3.1	11.8	12.6	34.5	19.7	84.0	91.5	93.0	94.0	83.5	89.2
6	8.0	36.7	12.4	24.5	42.6	93.0	41.8	64.5	90.5	91.0	87.5	78.0	82.3

(1) Nutrient plate counts incubated at 20° C for 4 days.

with either method of expressing the results for the Dec. 1st series, at which time the suspended solids concentration was reduced.

In comparing the various amounts of $CuCl_2$ it will be seen that the bacterial numbers per c.c. or per mg. suspended solids were highest in the sample containing 8.0 p.p.m. $CuCl_2$, the maximum treatment. The average results emphasize this fact more definitely.

The B.O.D. reductions with the various treatments were uniformily high, with the exception of the 8.0 p.p.m. $CuCl_2$ mixture, which gave low reductions October 24 and December first. These two results make the average B.O.D. reduction for this mixture appreciably lower than the others. The B.O.D. reductions for all the mixtures of the Dec. 1 series were lower than the average, due to the small amount of sludge carried in the mixtures.

It would appear from these results, therefore, that whenever the process is upset due either to low suspended solids or large amounts of copper, such upset is accompanied by high bacterial numbers and low B.O.D. reductions. Furthermore, $CuCl_2$ up to a concentration of 4 p.p.m. did not upset the equilibrium as indicated by the bacterial numbers and B.O.D. reduction.

II. *Effect of Suspended Solids Concentration of Activated Sludge Mixtures on Bacterial Numbers and Purification.*—The purpose of this experiment was to determine the effect on bacterial numbers and degree of purification of different suspended solids concentrations of activated sludge mixtures.

The experiment covers the period between Dec. 7, 1933 and Jan. 9, 1934. During this period six aeration tanks were maintained at various suspended solids concentrations by daily withdrawals of sludge and supernatant liquor prior to the addition of sewage. During the period from Dec. 7 to Dec. 30 the aeration period was 6 hours per day, aeration being stopped during the remaining 18 hours. From Dec. 31 to Jan. 9, inclusive, the sludge was aerated 16 hours and rested 8 hours. In addition to a number of other daily analyses, bacterial numbers were determined weekly in the mixtures. The suspended solids concentrations for those days and the number of bacteria per c.c. of the mixture and per mg. of suspended solids as well as the B.O.D. reductions are shown in Table II and Fig. 1. It will be seen that almost invariably bacterial numbers per mgm. of suspended solids decreased as the suspended solids concentration of the mixture increased. The B.O.D. reductions also increased with increasing suspended solids concentrations. But there was no definite numerical relation between bacterial numbers and B.O.D. reductions in the different periods. In other words B.O.D. reductions were not affected to as great an extent as bacterial numbers by varying the concentrations of suspended solids in the mixture (Table II). With

TABLE II.—*Suspended Solids, Bacterial Numbers and B.O.D. Reduction in Activated Sludge Mixtures of Various Concentrations*

	Dec. 8				Dec. 15				Dec. 22			
	Susp. Solids	Bacteria (1)		B.O.D. Red.	Susp. Solids	Bacteria (1)		B.O.D. Red.	Susp. Solids	Bacteria (1)		B.O.D. Red.
		Per C.C.	Per Mg.			Per C.C.	Per Mg.			Per C.C.	Per Mg.	
	p.p.m.			%	p.p.m.			%	p.p.m.			%
1	660	48.5	73.5	79.5	870	—	—	73.2	855	38.2	44.7	87.5
2	1095	45.5	41.6	83.0	1380	62.5	45.3	71.5	1175	30.9	26.3	90.5
3	1545	42.4	27.4	84.5	1935	49.5	25.6	81.0	1330	34.0	25.6	91.5
4	1970	31.8	16.1	88.0	2445	60.4	24.7	78.7	1860	32.7	17.6	91.5
5	2390	36.4	15.2	91.0	2990	19.5	6.5	80.5	2255	30.6	13.6	92.5
6	2940	57.6	19.6	91.5	3055	32.1	10.5	82.0	3470	24.2	7.0	92.0

(1) In Millions.
(2) Aerated 16 hours, others aerated 6 hours.

TABLE II (*Continued*)

	Dec. 29				Jan. 5				Average			
	Susp. Solids	Bacteria (1)		B.O.D. Red.	Susp. Solids	Bacteria (1)		B.O.D. Red.	Susp. Solids	Bacteria (1)		B.O.D. Red.
		Per C.C.	Per Mg.			Per C.C.	Per Mg.			Per C.C.	Per Mg.	
	p.p.m.			%	p.p.m.			%	p.p.m.			%
1	380	22.1	58.2	91.5	290	3.8	13.1	72.8	545	28.1	47.4	82.8
2	1005	18.0	17.8	94.5	800	2.6	3.2	74.7	1090	31.9	26.8	82.8
3	1400	17.0	12.1	92.0	1130	9.8	8.6	74.7	1470	30.5	19.8	84.7
4	2060	9.5	4.6	94.5	1870	3.0	1.6	76.0	2040	27.5	13.0	85.7
5	2335	21.2	9.1	94.5	2690	4.7	1.7	86.0	2530	22.5	8.8	88.9
6	3255	12.0	3.7	96.5	2695	1.7	0.6	90.0	3080	25.5	8.3	90.4

a wide range of bacterial numbers per mgm. of suspended solids, B.O.D. reductions of nearly equal magnitude were obtained.

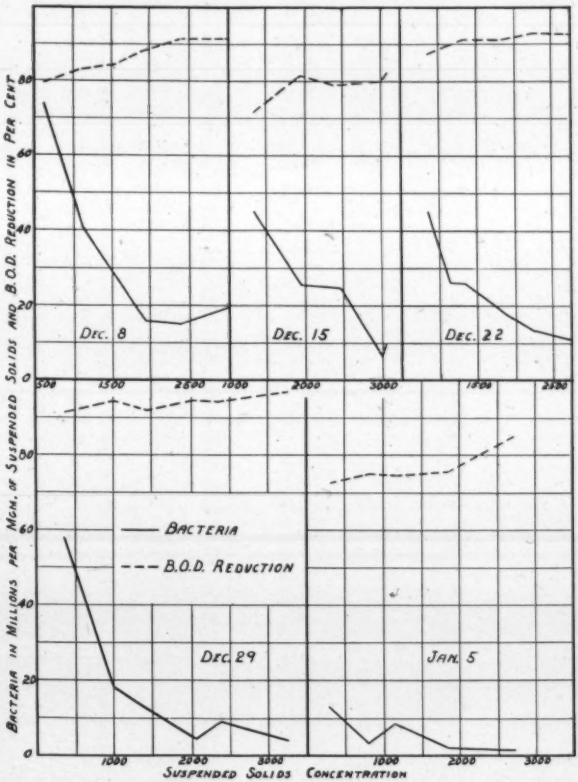


FIG. 1.—Effect of suspended solids concentration in aeration mixtures on bacterial numbers (in millions per mg. suspended solids), and B.O.D. reductions.

However, it should be borne in mind that the Jan. 5 series was aerated for a period of sixteen hours instead of six and is not strictly comparable with the remaining series. Furthermore, there are only a few cases where the bacterial numbers were high. Most of the counts were within

a narrow range of 5 to 25 millions per milligram of suspended solids. Those with higher ratios were in mixtures of low suspended solids concentrations.

The average results for the five tests show that increasing suspended solids concentrations have no effect on the bacterial numbers per c.c. but when computed per mgm. of suspended solids, the average bacterial numbers decreased regularly with increasing concentrations of solids. The average B.O.D. reductions show an appreciable increase with higher concentrations of solids.

TABLE III.—*Bacterial Numbers in Activated Sludge Mixtures Aerated for Different Periods*

Susp. Solids	Plate Counts in Millions Per Mg. Suspended Solids Hours Aeration				
	0	3	6	12	24
p.p.m.					
300	14.7	42.3	27.7	28.3	65.0
505	18.2	—	26.0	—	18.6
565	32.3	18.2	55.7	153.2	—
850	8.5	—	12.1	—	—
885	1.8	—	11.1	—	7.1
900	12.1	7.7	6.6	1.8	3.3
1150	10.4	11.9	24.0	190.0	—
1235	6.0	—	10.3	—	4.5
1370	6.0	14.0	5.7	—	—
1560	4.0	4.1	4.7	2.7	11.0
1685	4.8	—	11.9	—	1.4
1860	3.9	—	2.2	—	—
2190	4.6	6.1	6.6	5.7	—
2425	2.1	4.4	1.7	—	—
2610	8.8	—	3.6	—	1.2
2775	16.8	—	4.7	—	1.4
2930	4.3	2.1	2.3	0.4	2.3
3215	3.4	—	0.6	—	—
3225	4.4	2.3	2.8	1.5	—
3465	5.4	2.0	1.3	1.4	2.5
4310	4.4	1.7	1.8	1.2	—
4695	2.3	—	0.8		
5040	3.0	1.7	1.2	1.4	5.8

In Table III we have brought together in a tabular form the results from a number of experiments designed to show the effect of different aeration periods on the bacterial numbers of activated sludge mixtures of various suspended solids concentrations. The results are expressed as millions of bacteria per milligram of suspended solids originally present

in the mixtures. These mixtures were made at different times with different samples of sewage and activated sludge. The sewage was obtained from Plainfield and the sludge from Tenafly. Diffused air was used for aeration in all instances. The rate of aeration was controlled only by visual observation.

A study of the table will indicate that the changes in the bacterial numbers with the different periods of aeration were not uniform. Furthermore, sometimes the mixtures with low suspended solids concentrations contained fewer bacteria per mgm. of suspended solids than those with higher concentrations. In view of the differences in the character of the sewage and the sludge this lack of uniformity is not surprising. In spite of this, some general tendencies are apparent. In the first place, the mixtures with low suspended solids concentrations show a definite increase in numbers as a result of aeration. This increase comes sooner in some cases than in others or follows an initial decrease. With higher concentrations of suspended solids the numbers after aeration are generally lower than the original numbers. Furthermore, the numbers per mgm. of solids show a tendency to be generally low initially or after aeration while the numbers in mixtures of low concentrations are sometimes low and sometimes high. These tendencies are brought out more clearly in Table IV where the results are assembled arbitrarily into eight

TABLE IV.—*Bacterial Numbers in Activated Sludge Mixtures Aerated for Different Periods*

	(Plate Counts in Millions Per Mg. Suspended Solids)	
Susp. Solids	Hours Aeration	
p.p.m.	0	6
300–600	21.7	36.4
800–900	7.4	9.9
1100–1400	7.4	13.3
1500–2000	4.2	6.3
2000–2500	3.3	4.1
2600–3000	10.0	3.5
3200–3500	4.4	1.6
4300–5000	3.2	1.3

groups, each group, with the exception of one, being the average of three. Up to a concentration of 2,000 to 2,500 p.p.m. the numbers after 6 hours aeration are in excess of the original. Above this concentration the numbers after 6 hours aeration are less than the original.

In the next experiment an attempt was made to balance the numbers of bacteria in the sludge and supernatant portion of various mixtures, after 24 hours aeration, against the numbers added in the original sludge and sewage. From the volumes and numbers of bacteria per c.c. of the

sewage and the sludge introduced we determined the total numbers in the initial mixtures. After 24 hours of aeration the mixtures were settled for 30 minutes, and the volume of supernatant and sludge determined, as well as the number of bacteria per c.c. of each component. Thus we arrived at the total number of bacteria added and recovered in each component. This was done with five different concentrations of solids, obtained by increasing the amount of sludge added.

TABLE V.—*Changes With Aeration of the Bacterial Numbers of the Different Components of Activated Sludge Mixtures*

(Plate Counts in Millions)

	Mixture Susp. Solids	Bacteria Added			Bacteria Recovered After 24 Hrs. Aeration			% Decrease
		Sewage	Sludge	Total	Sludge	Supernatant	Total	
	p.p.m.							
1	500	85,600	4,600	90,200	239,400	14,400	253,800	+180
2	1200	85,600	17,600	103,200	73,400	7,800	81,200	21.4
3	1880	85,600	34,400	120,000	66,400	3,900	70,300	41.5
4	2490	85,600	61,600	147,200	73,900	4,200	78,120	47.0
5	3470	85,600	260,000	345,600	126,300	3,400	129,700	62.5

From Table V it can be seen that with 500 p.p.m. of suspended solids in the mixtures the numbers of bacteria in the sludge after 24 hours of aeration were far in excess of those added in the original sludge and the sewage. Furthermore, more bacteria were present in the supernatant than was the case with higher concentrations of suspended solids. Therefore, the sum of bacterial recovery was far in excess of that added. With 1200 p.p.m. of suspended solids, the numbers in the sludge after 24 hours of aeration were in excess of those added in the original sludge. The sum of bacteria recovered, however, was lower than that added. The 1880 and 2490 p.p.m. mixtures gave results similar to the preceding mixture, but the percentage recovery was lower. With 3470 p.p.m. suspended solids the numbers in the sludge after 24 hours were less than those added in the original sludge and therefore there was an overall reduction.

It is apparent, in the first place, that there is a transference of bacteria from the sewage to the sludge, because the numbers in the supernatant liquor in every case are lower than those in the sewage. This transference of bacteria from the sewage to the sludge is more complete with larger amounts of sludge in the mixture and hence fewer bacteria

are left in the supernatant after aeration with larger concentrations of suspended solids. Parallel with this transference there is the stimulating effect on the bacteria of the addition of new food in the sewage. The greater the amount of food in relation to the sludge, the greater the stimulation and the numbers of bacteria. It is also reasonable to assume

TABLE VI.—*Effect of Storage of Activated Sludge Mixtures Without Air on the Bacterial Numbers (In Millions Per C.C.)*

Suspended Solids	Initial	After 24 Hr.
p.p.m.		
290	3.8	16.0
380	22.1	14.7
800	2.6	11.0
855	38.2	24.2
1005	18.0	13.0
1130	9.8	9.5
1175	30.9	27.3
1330	34.0	60.0
1380	62.5	30
1400	17.0	32.9
1860	32.7	33.3
1870	3.0	4.5
1935	49.5	22.1
2060	9.5	13.6
2255	30.6	6.4
2335	21.2	27.3
2445	60.4	36.0
2690	4.7	7.3
2195	1.7	5.5
2990	19.5	30.2
3055	32.1	25.5
3254	12.0	9.7
3470	24.2	31.8

that a portion of the original sewage bacteria are killed and that fewer of the sewage bacteria are killed where there is less activated sludge. Thus the phenomenon observed is the resultant of two variables working in the same direction. The less the amount of sludge the greater the stimulation of bacterial growth due to food and less the tendency for original bacteria to die. Thus the improper balance of sewage to sludge has created an unbalanced condition resulting in the increase of bacteria beyond bounds and decrease in efficiency of purification. On the other hand, with high concentration of sludge (3470 p.p.m.), the amount of food added is not sufficient to maintain the bacterial numbers at the original level and hence a decrease occurs in the numbers of bacteria in the sludge after 24 hours of aeration. It is probable that a balance exists, wherein the numbers in the sludge do not increase excessively and

an overall reduction in the numbers of bacteria takes place. It would seem from these results that under the conditions of the experiment such a point was reached at 2500 p.p.m. suspended solids.

III. *Effect of Storage of Activated Sludge Mixtures Without Air on Bacterial Numbers.*—As the storage of activated sludge is known to affect the quality of the sludge, it was thought of interest to determine the effect of storage on bacterial numbers. It was thought that if a definite effect on the bacterial numbers could be noticed, it might be correlated with the quality of the sludge. Different sludge mixtures, after aeration, were allowed to stand quiescently in cylinders for 24 hours. The numbers of bacteria initially and after 24 hours of aeration were determined. Table VI gives the results of the counts arranged in the order of increasing suspended solids concentrations. These results are brought together from a number of series run independently of each other. In 11 instances a definite increase was noticed, in 10 other cases a decrease, 2 times there being practically no change in bacterial numbers, as can be seen in Table VII. The frequency of increases and decreases is not distributed in a regular way in respect to suspended solids concentration.

TABLE VII.—*Bacterial Numbers in Sludge Mixtures Grouped According to Increases or Decreases After 24 Hrs. of Storage*

Increases		Decreases	
Initial	After 24 Hr.	Initial	After 24 Hr.
3.8	16.0	22.1	14.7
2.6	11.0	38.2	24.2
34.0	60.0	18.0	13.0
17.0	32.9	30.9	27.3
3.0	4.5	62.5	30.0
9.5	13.6	49.5	22.1
21.2	27.3	30.6	6.4
4.7	7.3	60.4	36.0
1.7	5.5	32.1	25.5
19.5	30.2	12.0	9.7
24.2	31.8		
Av. 12.7	21.8	35.6	20.9

Generally speaking, however, sludge mixtures with initially high numbers undergo a decrease on storage, while those with low initial numbers give an increase on storage. Average numbers attained after 24 hours of storage tend towards the same level whether the numbers increase or decrease as a result of storage.

Discussion

Our objective in these studies has been to obtain some fundamental information regarding the changes taking place in bacterial numbers in the activated sludge process, and if possible to utilize the bacterial count in a practical way as a criterion and index of the condition of the sludge.

It is apparent from the foregoing description that not all the factors influencing the numbers of bacteria in activated sludge have been under control and that definite numerical values have not been obtained. But certain definite tendencies have been indicated.

It has been shown that the bacterial numbers are influenced by the concentration of suspended solids in the mixture. Generally the higher the suspended solids concentration in the mixture the lower the number of bacteria per unit amount of solids. This would indicate that a unit amount of solids in the activated sludge contains fewer bacteria than a unit amount of solids in the sewage. Since activated sludge is formed from sewage the numbers of bacteria become stabilized and reduced per unit amount of solids. A further conclusion may mean that in the mixtures of low suspended solids concentration instead of a reduction of the bacterial numbers an actual multiplication may take place, as has been indicated in Table V. The greater the load in relation to the amount of activated sludge the greater the disturbance and increase in bacterial numbers. On the other hand with high solids concentrations not only the sewage bacteria may be reduced but an actual reduction in the bacteria of the sludge may take place, due to lack of food and over-aeration.

That excessive numbers of bacteria may be caused by other factors, besides an improper balance between raw food and returned sludge, has been shown in the experiments with $CuCl_2$, where 8 p.p.m. $CuCl_2$ caused an increase in the bacterial numbers.

Whatever the cause that gives rise to excessive bacterial numbers, such increase is accompanied by reduced efficiency of purification. The purification as measured by B.O.D. reductions under experimental conditions is not affected to as great an extent as bacterial numbers.

The possible function of protozoa should also be taken into consideration in the explanation of these phenomena. If the numbers of bacteria-feeding protozoa are relatively few, as would be the case due to the partial antiseptic action of $CuCl_2$, or to insufficient amount of sludge, bacterial numbers would attain a high level. However, the presence of large numbers of bacteria feeders would tend to keep the bacterial numbers down, therefore inducing the bacteria to multiply at a greater rate. Purdy and Butterfield (1) have shown that the greatest oxygen consumption takes place when bacteria are in an actively multiplying stage rather than with high numbers of resting bacteria.

Summary

An attempt has been made to study the bacterial numbers of activated sludge mixtures under various experimental conditions. The following salient facts seem to be indicated from the results:

(1) $CuCl_2$ added to the aerating sludge mixture up to a concentration of 4 p.p.m. had no appreciable effect on the numbers of bacteria but 8 p.p.m. $CuCl_2$ resulted in a definite increase. This was accompanied by a somewhat reduced efficiency of purification.

(2) With low concentrations of solids in mixtures of activated sludge, the numbers of bacteria were generally high per unit amount of suspended solids but this relative increase of bacteria was accompanied by a lower purification efficiency.

(3) The effect of aerating sludge mixtures of low concentrations is generally an increase in bacterial numbers, while in sludge mixtures of high suspended concentration the bacterial numbers tend to decrease as a result of aeration.

(4) Storing activated sludge mixtures without aeration sometimes results in an increase and sometimes in a decrease of numbers of bacteria.

Reference

1. C. T. Butterfield and W. Purdy, "Some Interrelationships of Plankton and Bacteria in Natural Purification of Polluted Water." *Ind. & Eng. Chem.*, **28**, 213 (1931).

ADSORPTION AND FLOCCULATION AS APPLIED TO SEWAGE SLUDGES

By A. L. Genter

Consulting Chemical Engineer, Baltimore, Md.

The tenacity with which sewage sludges hold water against mechanical filtration pressure is undoubtedly due to the colloidal-capillary nature of the sludge particles themselves. Sewage sludges likewise exhibit a resistance to coagulation with relatively small amounts of such excellent flocculating agents as ferric and aluminum chloride. Prolonging the contact between the sludge solids and the surrounding liquid increases the coagulating and dewatering difficulties.

Fresh raw sludges require less ferric chloride for efficient coagulation than do raw sludges that are several days old, and these in turn require less ferric chloride than do digested sludges. It might be assumed that this is due to the presence of more colloidal matter in older raw sludges and digested sludges. However, the reverse is the truth. Sludge digestion so diminishes the amount of colloids present that the digested sludges dewater better on sand beds. Notwithstanding this fact, digested sludges in Baltimore and Chicago [1] require more coagulant per unit of dry substance for economic coagulation than do raw sludges. Hence the quantities of trivalent positive ions, used for the production of readily dewaterable floccules from various sewage sludges, cannot be taken as a measure of the nature and amounts of colloids present.

It is therefore the purpose of this paper to demonstrate that the well-known resistance of sewage sludges to coagulation with relatively small amounts of coagulating agents, is not so much due to the nature and amounts of colloids present as it is due to the soluble decomposition products generated in various sludges and accumulated in the liquid surrounding the sludge particles. The true sensitivity of the negatively charged colloids present in sewage sludges toward coagulants cannot be properly investigated unless the sludge particles are surrounded by water which is relatively free from such soluble decomposition products. When such investigations are made, the results are rather surprising.

Colloids, Adsorption and Flocculation

For the benefit of those readers who may be unfamiliar with the terminology relating to colloid chemistry, the following brief summary of the chief characteristics of colloids is presented.

The production of the colloidal state depends on subdividing matter

and giving it enormous surfaces with consequent, electro-adsorptive properties. This is called "dispersion." The destruction of this state depends on the discharge of these electro-adsorptive forces. This is called "flocculation."

Solutions involve the subdivision of matter as molecules in liquid solvents. In many cases the molecularly dispersed matter is further separated into electrically charged ions. Colloidal dispersions are ordinarily aggregations of molecules, and therefore are not in true solution. Dissolved matter can be separated from such colloidally dispersed matter by placing the mixture of both in a sack of parchment, collodion or Cellophane and immersing the sack containing the mixture in pure water. True molecules and solution ions will dialyse through these membranes into the pure water, while colloidal molecular aggregates will not. This process of distinguishing between matter in the truly dissolved and colloidal states, called dialysis, has retained its importance in colloid chemistry since its adoption by Graham in 1861.[2]

Due to the degree of subdivision, all matter in the colloidal state is characterized by enormous surfaces compared with the volume of the dispersed matter. Due to the enormously dispersed surfaces, considerable surface activity is manifested by colloids. The water layer surrounding colloids is also surface active. In fact, the surface activities existing between the liquid and solid interfaces produce all of the reactions known to colloid and capillary chemistry. These boundary forces are therefore of prime importance in studies of the water-holding properties of sewage solids.

Due to the mutual surface activity between capillary-active solids and water and its dissolved compounds, molecules and ions concentrate at the liquid-solid interface. This is purely an equilibrium phenomenon. Soluble portions of a colloidal wall either tend to dissolve in the surrounding water, or to attract matter already in solution, until equilibrium is reached. This concentration of ions, molecules or even molecular aggregates at such phase boundaries is called "adsorption."

If solution ions are selected by colloidal surfaces, a definite electric attraction exists, and "electro-" or "polar" adsorption takes place. Otherwise adsorption of molecules and molecular aggregates is termed "nonpolar" or "apolar." Thus negatively charged surfaces, such as those of sewage solids, will be selective toward positively charged ions, and vice versa.

Polar adsorption is akin to chemical reaction between solution ions. However, it is only a boundary relationship. Even the very active solution ions attract and carry water molecules with them.[3] They are hydrated by electronic forces. Colloidal surfaces become hydrated by related, boundary forces.

On account of the different degrees with which the surfaces of colloids become hydrated, colloids have been divided into two systems, *i.e.*, the suspensoid, or hydrophobic colloids having little affinity for water molecules, and the emulsoid or hydrophilic colloids, having decided hydration properties. The suspensoids are represented by a number of colloidal elements, many oxides, hydroxides and practically all sulphides. The emulsoids show a very strong hydration tendency and "imbibe" water or swell and surround themselves with a diffuse water coating. They set to clear gels which have a spongelike structure with ultramicroscopic capillaries. The capillary suction of silica gel, for instance, can exert a pull equal to several kilometers of water pressure.[4] Emulsoids include protein matter such as gelatin and albumin, also other substances such as starch, silicic acid, some soaps, and similar materials.

There are transition stages between the two systems and one might be in doubt about the classifications of some colloids were it not for the distinct difference between the electrical surface properties of the suspensoids and emulsoids.

In water relatively free from dissolved solids suspensoids show a decided coagulability with minute concentrations of electrolytes, especially the trivalent ions present in ferric and aluminum salts. Their particles have a definite electric potential toward the surrounding water and, according to the sign of the charge, move either toward the positive or negative electrodes under the influence of an electric current.

The stability of pure emulsoids depends on a small electric charge of their surfaces and hydration. Depriving them of their charge alone will not cause flocculation. Emulsoids ordinarily have very subordinate electric properties and a considerable stability toward coagulating ions. However, such emulsoids are never found unmixed with suspensoids in sewage sludges. Under such conditions, and by having a relatively high ash content, as is undoubtedly the case with sewage solids, they are highly sensitized to coagulants.

The sign of the charge of emulsoid surfaces can be readily changed from negative, at certain hydrogen-ion concentrations of the surrounding water, to positive at other hydrogen-ion concentrations. Furthermore, flocculated emulsoids can be returned to the colloidal state by continued contact with water after flocculation has taken place. Suspensoids do not show this property. Although continued stirring in the presence of water may coarsen a true suspensoid floc, such stirring may re-disperse an emulsoid floc. Flocculated sewage sludges cannot be held too long after contact with the coagulant. In all probability this is due to the presence of some emulsoids in such sludges.

When a surface in water is negatively charged toward the surrounding water, a similarity of surface charge on neighbouring particles causes

mutual repulsion and surface expansion. A partial discharge by oppositely charged solution ions starts surface shrinkage and coalescence. Complete discharge causes coagulation or flocculation. The orientation of the boundary ions is disturbed, and the charge simply disappears.

Sewage Colloids

Domestic sewage contains matter in various states of subdivision in water, from coarse, suspended solids down to porous organic colloids having capillary-active surfaces, and even down to true suspensoids and emulsoids, true solutions and electrolytes. The organic solid surfaces are constantly undergoing biological changes. As certain products of decay tend to go into solution, the colloidal structures containing these products will always turn the more soluble portions toward the water. These solids are therefore distinctly "ionogenic," *i.e.*, they generate their own solution ions.

Thirty years ago, Biltz and Krochnke [5] proved that sewage is rich in negatively charged colloids. In the light of modern colloid and capillary chemistry, not only the true colloids found in domestic sewage, but likewise the visible particles should be negatively charged relative to the surrounding water.

In the first place, it is a very general fact that the extreme layer of water adhering to any other phase, whether gas bubbles, immiscible liquid (such as oil and oil emulsions) capillaries of cellulose, starches, protein matter of bacteria or food residues, silica, insoluble fatty acids, soaps, humus substances, etc., is preferentially negatively charged.[6]

In the second place, the sulphides or polysulphides and amino acids, common to the surfaces of putrescible protein matter, result in the production of an active hydrogen ion in the particle walls which contain these substances. This is likewise true of protein waste residues in weakly acid or neutral and slightly alkaline surroundings. It is furthermore true of substances containing fatty acids and fatty acid salts common to sewage.

Such substances, common to most domestic sewage, explain why the particles should be negatively charged. The hydrogen ions generated by such fermentable and putrefactive substances have a great solution tension; when they go into solution they leave the surface of the solid particle negatively charged. The negatively charged particle is said to have an active or mobile hydrogen ion. Nernst, Haber and L. Michaelis [7] have expressed this action of solution tensions of cation and anion of various surfaces mathematically. Kruyt [8] graphically depicts this action of ionizable amino-acid linkages in protein colloids under the influence of acid and alkaline surroundings.

The negative wall charge is self-compensating, *i.e.*, it draws to the

solid-liquid interface, or adsorbs a diffuse water layer containing the mobile hydrogen ions, especially in the contaminated water common to sewage sludges. In colloid chemistry this adsorption layer, together with the wall charge, is the well-known Helmholtz electric double layer. The understanding of this double layer was extended by the researches of Gouy.[9] Thus this double layer is derived partly from materials already present in the particle itself, or generated within the particle. Under the action of an electric current, the particle with its immobile wall-charge migrates to the oppositely charged pole, and the adsorbed mobile ions of the diffuse liquid layer slip away and migrate in the opposite direction. Thus a wall layer of a negatively charged sewage particle acts as ionized matter. The relatively coarse particle, with its stationary, negative wall-charge acts as a huge multivalent anion (migrates to the positive pole) and the adsorbed, mobile liquid layer, with its positive ions, acts as a mobilized cation.

However, one must bear in mind that the liquors surrounding sewage solids are far from being pure water. They are relatively rich in foreign, dissolved salts and become richer in dissolved substances as the natural decay and putrefaction of the solids progresses. Such dissolved substances can be amino acids, fatty acids, amides, amines, ammonia salts of amino and fatty acids, and other simpler final putrefactive products such as ammonium bicarbonate, etc. Undoubtedly the negatively charged colloids and capillary walls act to adsorb these compounds in an electro-polar manner. Here the hydrogen ion either adsorbs oppositely charged ions, or it is completely displaced by certain other positively charged ions which become the adsorbed ions. The hydrogen ion is not displaced by alkali ions, but may be displaced by complex ions containing organically combined nitrogen [10] which in turn are displaced by ions of heavy metals. In some mixtures of electrolytes, some ions may increase the adsorption of those that are ordinarily weakly adsorbed. Some amino acids are more strongly adsorbed from mixtures with polypeptides than they are from pure solution.[11] Most adsorption is a displacing or exchange phenomenon as shown by Freundlich and Neumann.[12]

Flocculation, involving the complete discharge of the wall potential, is also an exchange reaction as shown by the same investigators and others.[13] When ferric chloride solution is added to sewage sludges, surrounded by pure water, the wall preferably adsorbs ferric ions because of the multivalent, positive ferric ion charge and the charge on the particle disappears. At the same time, hydrogen ions are no longer adsorbed by the wall so that they replace the ferric ions that have been adsorbed in flocculation and unite with the remaining chlorions to form hydrochloric acid. Thus an acid reaction follows such flocculation.

Flocculation is, therefore, akin to chemical precipitation. However, as before emphasized, it is nothing but a boundary kinship. The constituent elements entering into reactions involved in colloidal flocculation do not combine in definite, predictable proportions as in the chemistry of solutions. Neither the reaction nor the floc produced by coagulation can be expressed by any stoichiometric formulae.

Due to the fact that the potential of the wall-charge is entirely independent of the size of the colloidal particle, very minute quantities of electrolyte are needed for potential discharge and flocculation when ordinary colloids are surrounded by relatively pure water.

If the adsorbed ions are such that they react chemically with any coagulant, *e.g.*, when ammonium ions, amino-acid ions and their associated bicarbonate and similar ions are adsorbed by the walls of sewage solids, and ferric chloride is used as a coagulant, the ferric ions will be chemically consumed in reacting with such "ammoniacal" ions, both in solution and held by adsorption. Ferric chloride reacts with ammonium bicarbonate to liberate carbon dioxide gas and form ammonium chloride and hydrated ferric oxide. Two mols of ferric chloride will dissolve nine mols of this freshly precipitated oxide to form colloidal basic ferric chloride and a further excess of chlorion will form ferri-ammonium chloride $(NH_4)_2\ FeCl_6$. Even with the relatively abundant amounts of ammonium bicarbonate found in well digested sludges, the latter compound may be readily formed by additions of ferric chloride necessary for the formation of a filtrable floc. Furthermore amino acids form salts and double salts with ferric chloride. These compounds are water soluble. It will therefore require an excess amount of ferric chloride to provide for these or similar reactions and to discharge the wall potential of the colloids present. These parallel reactions may lead to very erroneous conclusions and decided irregularities in an attempt to reduce observations of sludge flocculation to colloidal chemistry.

Practically all organic solids common to various sewage sludges are ionogenic. As new surfaces are exposed through particle decomposition, the same electro-polar surface properties come into play toward the liquid that covers their surfaces, and new adsorption equilibria are brought about.

In all cases the negative wall-charge remains, and the diffuse, mobile "ionic atmosphere" held by adsorption predominates in varying degrees in ions and dissolved substances that react with most coagulants, especially ferric ions, to form chemical precipitates or soluble amino and ammoniacal coordination compounds, before any actual flocculation takes place.

Adsorption and Elutriation

The process of adsorption in dilute solutions, free of substances that may cause parallel chemical reactions, is nothing but a simple equilibrium reaction. This is true whether the constituents of a solution are being removed by activated carbon or by any other surface-active substances such as those found in sewage sludges, or whether such adsorbed ions are those of ferric coagulants used for flocculation.

Adsorption determinations with substances like charcoal are simple. The adsorbent is weighed and mixed with a known volume of solution containing a known amount of the dissolved compound to be adsorbed. The mixture is shaken and left in contact for a predetermined time, then the adsorbent is removed by decantation, centrifuging or ultrafiltration. The concentration of dissolved substance left in the clear solution is then again determined.

If (m) is the amount of adsorbent present, (c) is the concentration of dissolved compound left in the equilibrium liquid after adsorption, and (x) is the amount of this compound removed by adsorption, then the equilibrium process should be quantitatively expressed by the Freundlich equation for the adsorption isotherm:

$$x = m\ k\ c^{1/n} \text{ or } \frac{x}{m} = k\ c^{1/n}.$$

This is an empirical parabolic equation, wherein (k) and (n) are constants, characteristic of the substance adsorbed. Hence the expression (x/m) represents the amount of substance adsorbed per unit of adsorbent present. This is measured in any convenient manner, such as direct percentage, millimols of dissolved substance per gram of adsorbent, etc., (c) can be measured in mols, millimols, parts per million or in any other convenient manner.

By plotting the values of (x/m) as ordinates and the equilibrium concentrations (c) as abscissae, the typical parabolic adsorption isotherms of Fig. 1 are obtained. These are taken from Rona and Michaelis [14] and show how the electrolytes NaCl and $AlCl_3$ in solution are taken up by blood charcoal. Sodium chloride is taken up more weakly than aluminum chloride.

With most adsorbents the maximum value of such graphs can be a rather flat line representing saturation conditions. With weakly adsorbed substances negative adsorption can develop at higher solute concentrations so that the curve reverses. This simply means that the adsorbent starts to take up more water than dissolved substance, which increases in concentration in the equilibrium liquid, resulting in negative adsorption. The more strongly adsorbed ions give adsorption isotherms of a steeper slope.

As adsorbents and their adsorbed compounds are always in equilibrium with the dissolved substances in the surrounding liquid, it will be seen that this equilibrium can be readily disturbed by simple dilution. In the matter of clean adsorption, adsorbed compounds can be smoothly washed out by simple dilution. Such washing is nothing but

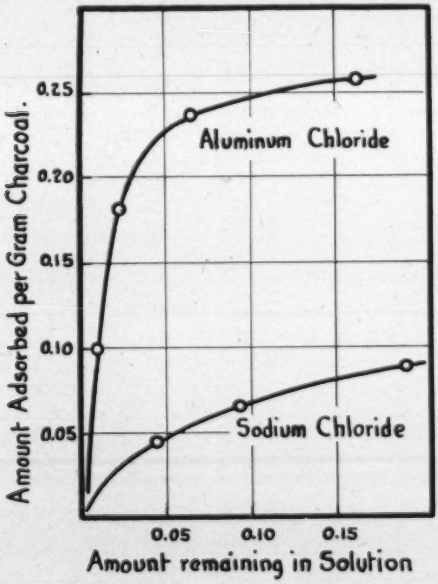


FIG. 1.—Adsorption isothermals of two electrolytes.

the opposite of adsorption, *i.e.*, "washing is, in fact, nothing but following the adsorption isotherm in the opposite direction; by repeatedly pouring water over the adsorbent, we get equilibrium liquids of fairly high concentration which are then removed."[15]

Applied to sewage sludges, this is the basic idea incorporated in the *Genter Sludge Treatment Process* for diminishing the concentration of soluble decomposition products in various sewage sludges in order to reduce materially the amount of coagulant necessary for the production of dewaterable sludge floccules. The writer prefers the term "elutriation" to "washing" in describing this reversal of adsorption, because

its meaning includes the entire process of cleansing by dilution, mixing and decanting.

The equilibrium liquids obtained by elutriation are therefore termed "elutriates." They rapidly accumulate dissolved and adsorbed putrefactive and decay compounds. In its simplest form the procedure of producing such elutriates consists in diluting any crude, primary, secondary waste-activated sludge, or digested sludge, or any of their mixtures with water that is comparatively free of compounds tending to react chemically with a coagulant, thoroughly mixing the water and the sludge and thus diffusing the dissolved and adsorbed compounds into the dilute solution, and allowing the solids to subside again into a sludge. The elutriated sludge will then have a materially lower concentration of such soluble compounds. The elutriate is decanted and preferably returned to the raw sewage entering the sewage works. "Owing to the peculiar shape of the adsorption isotherm, the effectiveness of washing decreases disproportionately as the amount retained by the adsorbent becomes smaller."[15] This simply means that due to the shape of the isotherm (Fig. 1), the effect of adsorption is greatest in very dilute solutions.

Fortunately, however, as will be seen from flocculation graphs obtained on various sludges, the saving in coagulants is in direct proportion to the amounts of such "ammoniacal" compounds removed from any sludge by elutriation. Elutriating any sludge containing relatively large amounts of such dissolved compounds, in one or two volumes of water that is relatively pure, will remove one-half and more of the detrimental compounds and cut the coagulant consumption necessary for producing dewaterable sludge floccules more than in half.

In the *Genter Sludge Treatment Process* the chemical removal of such ammoniacal compounds can also be employed, preferably combined with elutriation. This procedure may be of particular advantage with sludges containing adsorbed, detrimental compounds, under very dilute conditions, such as some waste activated sludges and mixtures of fresh raw and waste activated sludges. Here the adsorbed amino and ammonia complexes can be either chemically destroyed or chemically changed into very simple and soluble products, which are then removed more easily by elutriation, as their adsorption isotherms can be made to take a flatter slope. Larger ions with multiple charges are preferentially adsorbed in very dilute solutions; simple charges of smaller ions are preferentially adsorbed in more concentrated solutions. Adsorbed, complex protein products and amino acids may be readily changed into simple ammonium chloride and even into cyanides by the proper action of chlorine and hypochlorites. These simpler compounds are easily removed by elutriation.

Due to the very nature of the closed-circuit course of the biological flocculi in the activation process, these flocculi have been subjected to repeated washings and contain adsorbed compounds in a dilute solution, which is in well established equilibrium with the biological flocculi. Notwithstanding this fact, the flocculi are highly ionogenic and can be elutriated in water that is not in equilibrium with the flocculi. This necessitates the use of pure water, or water containing various inexpensive chemical aids, or exchange adsorbents. Primary sludges, containing both crude solids and waste activated sludge, and ordinary raw sludges are amenable to elutriation treatment. Digested sludges, due to their lower content of ionogenic solids and relatively high content of readily soluble ammoniacal compounds, are most sensitive to such treatment.

This paper is intended to show that diminishing the concentration of soluble putrefactive products in sewage sludges by simple elutrition materially reduces the amounts of ferric coagulants necessary for efficient flocculation. Furthermore, it is intended to show that any incidental removal of true colloids from sewage sludges by simple elutriation has no detectable economic influence on coagulant saving.

In the following discussion relatively few of the numerous laboratory investigations are tabulated and shown in graphic form. Those investigations using chemicals as an aid to elutriation and coagulants, other than ferric chloride, have been omitted. Ferric chloride has proved to be the most effective coagulant for unelutriated and elutriated sludges. The reason for this evidently lies in the fact that, although the chlorion of this compound is of the same charge as that of the colloidal wall, it is monovalent and, in the presence of the trivalent ferric cation, it plays a very subordinate role. This is not true with ferric sulphate, for here the anion is bivalent and plays a more important role. It tends to increase the negative potential of the wall-charge, thus acting more strongly against the discharging effect of the ferric ion.[16] Chlorinated copperas, for the same reason, will be more effective than ferric sulphate, but less effective than ferric chloride.

Experimental Procedure

The degree of flocculation of a colloid can be demonstrated by the rate of cataphoresis (*i.e.*, migration of the suspended particles under the influence of an electric field) at different coagulant concentrations.[17] Furthermore, the weight of colloids settled per minute may be plotted as ordinates with various coagulant additions as abscissae. This latter method is but a variation of the method adopted in the investigations at the Baltimore sewage works.

The degrees of flocculation of sewage sludges can be readily measured

by simple filtration tests. Such tests were adopted at Baltimore. Using the arbitrary 200 g. sludge samples and filtering in a Buechner funnel to a point where the vacuum broke, gave data which had a strictly empirical advantage. It was found that the time required to produce a vacuum break at any given coagulant dosage, under the experimental conditions, was quite similar to the time of filtration on a continuous vacuum filter. More than two thousand filtration tests were made on various sludges in the laboratories of the Baltimore sewage works by this method and, as the results were substantiated on a much larger scale in the field, it is felt that the laboratory technique evolved was quite reliable.

The laboratory procedure involves collecting several liters of sludge and using 200 g. samples for each filtration test. These tests were made with a 9 cm. Buechner funnel, No. 4 grade Whatman filter paper, a filter flask attached to a Schuette Koerting laboratory tap aspirator and a mercury column vacuum gauge. This particular aspirator was able to produce a 29-in. vacuum. However, the mercury column was not always used as a measure of the vacuum produced, but rather as an excellent means of indicating when any particular filtration test was completed.

The 200 g. sample of sludge was treated with ferric chloride, poured onto a previously moistened filter paper in the Buechner funnel and, simultaneously with the opening of the stop-cock connecting the filter flask with the aspirator a stop watch was started. After a certain time, the sludge cake separated from the walls of the filter, thus allowing air to pass into the filter flask. This contraction limit showed instantly on the mercury gauge and the stop-watch reading was recorded.

In order to keep the total amount of sample filtered always constant when adding various percentages of coagulant, a maximum limit of 220 g. of mixture of sludge, coagulant and distilled water was used. The difference between the 200 g. of sludge and ml. of added coagulant was made up with distilled water in order to bring the total up to 220 g. This 20 g. limit above the 200 g. solid sample permitted using as high as 15 per cent ferric chloride on solids present. Thus the tests could be extended over a wide range of coagulant dosages when using a 10 per cent ferric chloride solution.

Every 200 g. sludge sample was weighed in a tared beaker on a sensitive pulp balance. The ferric chloride was added from a titration burette, then the total weight brought to 220 grams with distilled water. The mixture was then stirred with a hard rubber spatula for one minute, and the contents of the beaker poured into the Buechner funnel, wherein a wetted filter paper had already been sucked into position on another filter flask. The coagulated sludge adhering to the walls of the beaker was removed by a spatula. The vacuum control cock was then opened

and the filtration rate determined. The filtrate was measured after each test and the cake weighed if necessary. However, it was soon discovered that by deducting the amount of filtrate obtained during each test from the total 220 grams filtered, the remaining weight of cake was equally as accurate as that obtained by actually removing and weighing the cake.

The various percentages of ferric chloride, related to dry volatile solids in the sample, were plotted as abscissae, and the actual filtration velocities in grams of filtrate and cake, or in grams of dry solids alone, per minute as ordinates.

Baltimore City tap water was generally used for elutriation tests. The pH of this water varied from 7.8 to 8.4. Elutriation tests on some sludges were also conducted when using settled sewage which contained as high as 30 p.p.m. nitrogen from ammoniacal compounds. Distilled water was used in most of the dialysis tests.

Sludges were usually elutriated in 5 gallon bottles. Thus 8 or 10 liters of a sludge sample might be measured out and poured into such a bottle and an equal volume of tap water poured on top of this sludge and the contents thoroughly mixed. The solids were then allowed to settle to the original volume, and the supernatant elutriate was syphoned off and sampled. Filtration tests were run on the elutriated sludge. The remainder in the bottle was again elutriated and tested and so on. By this means the entire sludge sample was exhausted and a set of curves obtained on sludges that had been given successive elutriation treatments.

As such elutriation procedures removed some colloids from digested sludges, samples of the same sludges were dialysed in order to remove soluble ammoniacal compounds without removing colloids. The sludge was placed in sacks of parchment and Cellophane and immersed in distilled water. This water was frequently changed.

As elutriation proceeded more rapidly and with much less water consumption than did dialysis, it was an easy matter to collect sludge samples for filtration tests from the dialysis cells, when comparative tests with the dialysed sludges showed approximately the same ammoniacal contents.

In order to study the influence of soluble ammonium compounds and amino acid on coagulant consumption, well elutriated sludges were treated by adding known amounts of ammonium carbonate, carbamate, and an amino acid in order to produce sludges containing about the same ammonia or amino-ammonia nitrogen that was present in the original, unelutriated sludge samples.

Practically all sludges were tested for solids by evaporation, volatile matter, pH, and soluble amino-ammonia nitrogen. This latter value

is shown as AAN in the following tables. Elutriates were sampled for amino-ammonia nitrogen, pH, and occasionally for 5-day B.O.D. and suspended solids.

Considerable time was consumed in the laboratory in finding a rapid and reliable method of determining the soluble ammoniacal compounds present. It was found exceedingly difficult to distill ammonia from causticized sludges, due to frequent and excessive foaming. The method was slow and it was difficult to obtain check results. Furthermore it was thought that certain amino acids would hydrolyse and form ammonia by such treatment. Distilling causticized samples of centrifuged sludge liquors was found to be most unreliable. The van Slyke method of liberating nitrogen from these compounds in the presence of sludge solids was quite unreliable. Nesslerization of sludge liquors in the absence of the solids was also unreliable. The use of hypobromite for the liberation of nitrogen was quite reliable on digested sludges, but was not so accurate on raw sludges.

As soluble ammoniacal compounds in sewage sludges are adsorbed by the solids from the surrounding solution, these compounds are distributed between the solids and the liquid in equilibrium proportions and cannot be completely filtered or otherwise removed from the solids. Hence it is desirable to use a method that is satisfactory in the presence of the insoluble sludge solids.

The Henriques-Sørensen formalin titration method[18] used in organic and physiological chemistry for the determination of amino-ammonia nitrogen, was found to be reliable in the presence of sewage solids. This method had to be modified to provide for thorough exchange adsorption and liberation of amino-ammonia compounds, but repeated check tests showed that it gave results closer to those obtained by distillation of causticized sludges than any rapid test that had been tried.

This modified method will be detailed in a later paper. The principle depends on the fact that a neutral formalin solution reacts with both ammonium salt solutions and amino acids to form methylene condensation products and to liberate the acids to which the ammonium is bound, and the acid character of the amino acid. These resulting acids are, therefore, readily titratable with N/10 or N/100 NaOH solutions.

As both the amino acids and the ammonium compounds were found to be active in chemically consuming ferric coagulants, no attempt was made to determine the distribution of the amino-ammonia nitrogen in all sludges. Hence the nitrogen figures relating to these soluble products are always indicated as AAN, *i.e.*, amino-ammonia nitrogen. In some raw sludges the distribution showed slightly more ammonia nitrogen than amino acid nitrogen. In digested sludges ammonia nitrogen

predominated. In a sample of activated sludge obtained from Hagerstown, Md., practically no ammonia was found. In order to avoid decomposing amino acids, determination of ammonia on this sludge was made by the Folin method.[19]

Results of Experiments

The data reported herewith cover typical investigations of digested, raw and activated sludges.

Table I.—*Digested Sludge from Heated Digestion Tank C-11*

% Solids in Sludge..... 6.30	pH of Sludge..... 7.4
% Volatile in Sludge..... 55.30	pH of Sludge Liquor..... 7.7
A–A Nitrogen in Sludge..... 950.	Grams Solids in Sludge..... 12.6

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	5.12	73	147	220	6	15	35.20	6.8
2	5.85	69	151	220	4	08	53.20	6.4
3	6.59	69	151	220	2	24	91.70	6.2
4	7.32	68	152	220	1	41	130.70	5.9
5	8.05	69	151	220	1	33	141.93	5.7
6	8.78	69	151	220	1	28	156.80	5.5
7	10.25	69	151	220	1	23	159.10	5.0
8	10.98	69	151	220	1	20	165.50	4.8
9	11.71	69	151	220	1	26	153.52	3.9
10	12.44	70	150	220	1	31	144.70	3.6
11	9.52	69	151	220	1	23	159.10	5.0

Results With Digested Sludges.—Table I shows the results obtained with a well-digested sludge from a heated digestion tank. The digestion temperature had reached approximately 90° F. before this sample was collected. As a result the ammoniacal nitrogen was relatively high for digested sludge at the Baltimore Sewage Works. It required about 11 per cent anhydrous $FeCl_3$, based on dry solids, to produce complete flocculation and a maximum filtration rate.

Table II shows similar data, using the same digested sludge, after 8 liters of the sludge had been well mixed with 8 liters of Baltimore City tap water and the sludge allowed to settle for about 20 hours, in order to avoid removing coarser colloids in the elutriate. It will be seen that the suspended solids in the elutriate are rather low. After conducting flocculation tests on a portion of this sludge, the balance was given another elutriation.

TABLE II.—*Same Digested Sludge Elutriated. 1 Vol. Sludge to 1 Vol. Tap Water*

% Solids in Sludge..... 5.72	pH of Sludge..... 7.0
% Volatile in Sludge..... 55.29	pH of Elutriate..... 7.7
A–A Nitrogen Sludge.....570.	Grams Solids in Sludge..... 11.44
A–A Nitrogen Elutriate.....200.	p.p.m. Suspended Solids in Elutriate.....196.
B.O.D. (5 day) Elutriate..... 87.	

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	5.64	69	151	220	1	23	158.40	6.3
2	4.83	71	149	220	1	44	127.00	6.4
3	4.03	67	153	220	2	49	78.10	6.5
4	3.23	64	156	220	7	38	28.80	6.8
5	6.45	68	152	220	1	10	188.50	5.5
6	7.26	68	152	220	1	08	194.18	5.2
7	8.06	68	152	220	1	06	200.00	4.7
8	8.86	68	152	220	1	11	185.97	4.0

TABLE III.—*Same Digested Sludge Elutriated. 1 Vol. Sludge to 2 Vols. Tap Water*

%Solids in Sludge..... 6.41	pH of Sludge..... 7.0
%Volatile in Sludge..... 53.96	pH of Elutriate..... 7.6
A–A Nitrogen Sludge.....280.	Grams Solids in Sludge..... 12.82
A–A Nitrogen Elutriate.....185.	p.p.m. Suspended Solids Elutriate.....177.
B.O.D. (5 day) Elutriate.....196.	

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	2.89	61	159	220	1	37	136.17	5.8
2	2.18	60	160	220	2	50	77.65	6.0
3	1.44	58	162	220	9	52	22.29	6.9
4	3.60	62	158	220	1	16	173.63	5.4
5	4.31	62	158	220	1	08	194.17	5.1
6	5.03	62	158	220	1	08	194.17	4.7
7	5.75	62	158	220	1	15	176.00	4.3
8	6.47	62	158	220	1	18	169.23	4.1

Table III shows the results of this sludge after a second thorough mixing with water, settling and decantation of the elutriate. This sludge, when compared with the original sludge of Table I, required less than half the amount of $FeCl_3$ for complete flocculation and maximum filtration rate.

TABLE IV.—*Same Digested Sludge Elutriated. 1 Vol. Sludge to 6 Vols. Tap Water*

% Solids in Sludge..... 6.77	pH of Sludge..... 6.8
% Volatile in Sludge..... 53.77	pH of Elutriate..... 7.4
A–A Nitrogen Sludge.....100.	Grams Solids in Sludge.....13.54
A–A Nitrogen Elutriate..... 30.	

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	1.36	61	159	220	2	42	81.48	6.0
2	0.68	58	162	220	9	15	23.78	6.7
3	2.05	56	164	220	1	46	124.50	5.8
4	2.73	59	161	220	1	23	159.07	5.4
5	3.40	58	162	220	1	18	169.23	5.2
6	4.08	58	162	220	1	14	179.23	4.8
7	4.76	62	158	220	1	12	183.33	4.0
8	5.45	60	160	220	1	28	149.96	3.3
9	6.13	62	158	220	1	30	146.66	3.0

Table IV shows the results of further elutriation of the sludge remaining from previous elutriation tests. The effectiveness of elutriation decreases disproportionately as the amount of adsorbed compounds retained by the sludge becomes smaller.[15] It will be noted that the pH of the heavy sludge has gradually dropped from 7.4 of the original sludge to 6.8 of the well washed sludge, notwithstanding the fact that this sludge was washed with tap water having a pH of 8.2.

The graphs showing the degree of flocculation obtained on the sludges of Tables I to IV are drawn in the full lines of curves (*A*), (*B*), (*C*) and (*D*) of Fig. 2.

Notwithstanding the long settling periods allowed the elutriated sludges of Tables II, III and IV and graphs (*B*), (*C*) and (*D*) of Fig. 2, dialysis tests were made on portions of the same sludge, in order to eliminate the effect of removing some colloids by elutriation. (See Tables V and VI.)

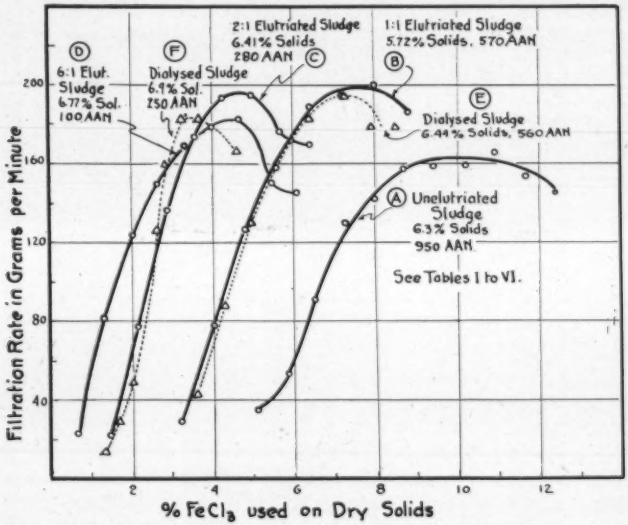


FIG. 2.—Effect of elutriation and dialysis on digested sludge.

TABLE V.—*Same Digested Sludge as in Table I. Dialysed with Distilled Water to Reduce Amino-ammonia Nitrogen to approximately that of Elutriated Sludge of Table II*

% Solids in Sludge..... 6.44	pH Sludge..... 6.9
% Volatile in Sludge..... 54.44	Grams Solids in Sludge.....12.88
A–A Nitrogen Sludge.....560.	

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	5.00	69	151	220	1	41	130.72	6.0
2	4.29	66	154	220	2	30	88.00	6.3
3	3.58	64	156	220	5	10	42.58	6.5
4	5.73	68	152	220	1	22	160.93	5.7
5	6.44	72	148	220	1	12	183.33	5.3
6	7.16	72	148	220	1	08	194.17	5.1
7	7.87	73	147	220	1	14	179.23	4.8
8	8.59	72	148	220	1	14	179.23	4.1

TABLE VI.—*Same Digested Sludge as in Table I. Dialysed to Reduce Ammoniacal Nitrogen to Approximately that of Elutriated Sludge in Table III*

% Solids in Sludge..... 6.90	pH Sludge..... 6.9
% Volatile in Sludge..... 54.55	Grams Solids in Sludge.....13.80
A–A Nitrogen Sludge.....250.	

Test No.	% $FeCl_3$ on Solids	Grams Wet Cake	c.c. Filtrate	Total Grams	Time Filtering		Filtration Rate p/min.	pH Filtrate
					Min.	Sec.		
1	1.33	66	154	220	15	30	14.19	6.7
2	2.00	60	160	220	4	32	48.53	6.2
3	2.67	70	150	220	1	44	126.94	5.8
4	3.34	71	149	220	1	12	183.33	5.5
5	4.00	72	148	220	1	14	179.23	5.2
6	4.67	70	150	220	1	20	165.04	4.9
7	3.67	70	150	220	1	12	183.33	5.3
8	1.67	68	152	220	7	46	28.32	6.4

As aluminum, iron and calcium salts were found in the distilled water, after dialysis of the sludge, it was believed that the dialysed sludges should filter more slowly or with slightly higher $FeCl_3$ consumptions than elutriated sludges, because some positive coagulating ions had actually been removed by dialysis. However, such an effect did not occur. It may show up if dialysis is carried to extreme limits. As it is unnecessary in actual practice to carry elutriation of such sludges much beyond the limits of 2 parts of elutriating water to 1 part of digested sludge, dialysis need not be carried beyond the same AAN concentration for the purpose of studying the effect of removal of colloids by elutriation.

A casual study of Fig. 2 might lead to the opinion that the results show a very slight difference between elutriated and dialysed sludges. However, if the actual grams of dry solids separated per minute by filtration are plotted as ordinates against the per cent $FeCl_3$ used, based on dry solids, Figure 3 results. The data shown by these curves would indicate that the dialysed sludges flocculated better than elutriated sludges. However, this difference can easily be due to slight differences in dry solids or to the use of tap water for elutriation and distilled water for dialysis. In any case, the removal of some colloids by elutriation of digested sludges in Baltimore has no effect on actual coagulant saving.

Figure 4 shows further data obtained on digested sludges taken from the same digestion tank at a different time. Elutriation was carried further than in preceding experiments. Although this sludge was

collected a month earlier than that used in the preceding tests, the relative positions of curves on Figs. 2 and 4 are not essentially different.

The effects of coagulant overdosage in Graph (*A*) of Fig. 4 produce a curve reversal that does not have the characteristics of the "irregular series" [20] in flocculation studies, which will be presently discussed. That

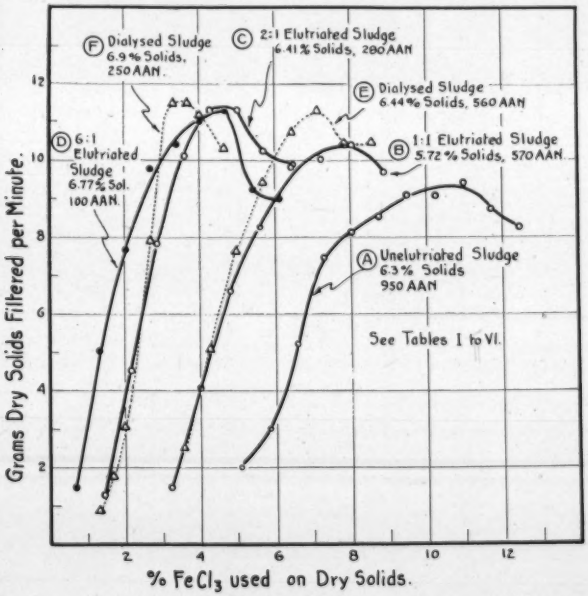

(F) Dialysed Sludge 6.9% Solids, 250 AAN.
(C) 2:1 Elutriated Sludge 6.41% Solids, 280 AAN
(E) Dialysed Sludge 6.44% Solids, 560 AAN
(D) 6:1 Elutriated Sludge 6.77% Sol. 100 AAN.
(B) 1:1 Elutriated Sludge 5.72% Solids, 570 AAN
(A) Unelutriated Sludge 6.3% Solids 950 AAN
See Tables I to VI.
Grams Dry Solids Filtered per Minute.
% FeCl3 used on Dry Solids.
2
4
6
8
10
12

FIG. 3.—Flocculation values and filtration rates of Fig. 2 related to solids only.

this reversal is more the effect of ammonium salts is evident from the curve shown in dotted lines near Graph (*A*) of Fig. 4. Here the well elutriated sludge (*E*) was treated with ammonium carbonate which contained some ammonium carbamate, in order to make the well elutriated sludge contain approximately as much AAN as the original sludge. A curve showing a lower filtration rate, but of very similar shape and coordinate location, resulted.

Another portion of the well elutriated sludge (*E*) was treated with sodium bicarbonate and permitted to stand 16 hours. Sufficient sodium

bicarbonate was added to make the amount of CO_2 present approximately the same as that added with the ammonium carbonate added in the previous experiment and to bring the pH of the sludge back near that of the original unelutriated sludge. Permitting the sludge to stand 16

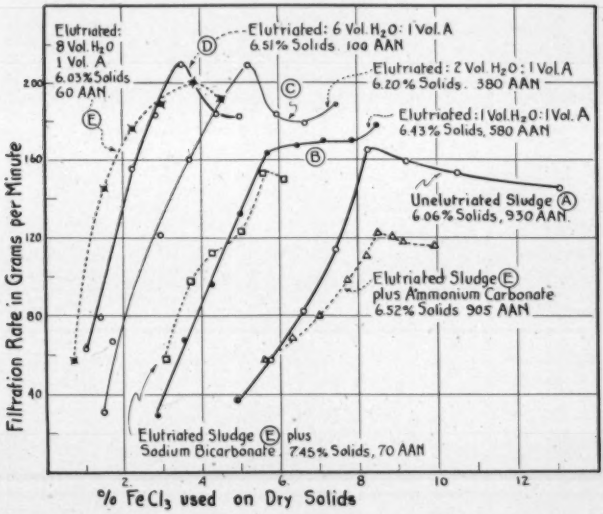


FIG. 4.—Effect of successive elutriations on digested sludge and retreatment of elutriated sludge with ammonium carbonate and sodium bicarbonate.

hours, under the influence of this alkaline salt, slightly increased the ammonia content so that the AAN was 70 p.p.m. Quite evidently the sodium bicarbonate reacted with the ferric chloride to form ferric hydroxide and to slow up filtration, as well as consume coagulant, although not to the extent resulting from the use of ammonium carbonate.

Bringing the ammoniacal content of a digested sludge, that has been well elutriated, back to approximately the same as that of the original unelutriated sludge, is but another way of showing that, compared to the removal of ammoniacal salts by elutriation, the accidental and simultaneous removal of some colloids has little or no effect on ferric chloride consumption. This is again evident from the following.

The 2:1 elutriation, shown in curve *C* of Fig. 4, was of two hours duration only, as by that time the sludge had settled back to its original

volume in the 5-gal. bottle used for elutriation. The suspended solids in this elutriate were 720 p.p.m. A sample of the same elutriate, taken several hours later, showed 320 p.p.m. The elutriates from well digested sludges became clear much more rapidly than from digested sludges containing relatively fresh settled solids.

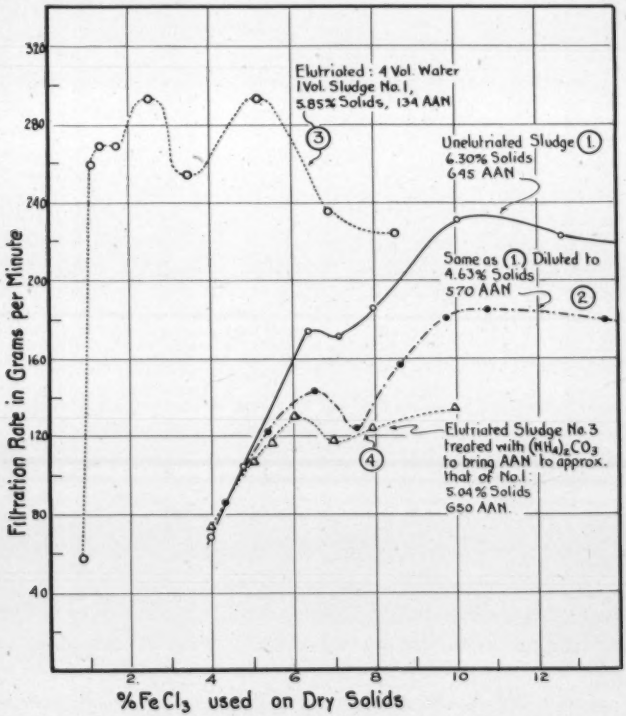


FIG. 5.—Effect of coagulant overdoses of elutriated and unelutriated sludges.

When ferric ions are strongly adsorbed by a negatively charged surface, their discharging action subordinates the opposite effect of the negative chlorions, until actual flocculation occurs. Further additions of ferric chloride then tend to make the surface adsorb negative chlorions

in the mobile layer and the surface becomes positive to the surrounding liquid. Continued ferric chloride additions may again reverse the charge. This is an example of what is known as the "irregular series." [20] It will always occur when the potential-lowering effect of the positive ion is far in excess of the potential-raising effect of the negative ion, and is characteristic of the effect of ferric chloride on a great many true colloids.

This irregular effect on unelutriated and well elutriated sludges as well as ammoniated-elutriated sludge is shown by curves 1 to 4 of Fig. 5.

The digested sludge of these tests was collected and tested almost a year previous to the foregoing tests. The AAN content of the sludge was rather low. Although excessive overdoses of coagulant were tried, no true, reversible graph could be obtained. The first break that occurs in curve (1) of Fig. 5 is most likely very similar in cause and nature to the break that occurs in curve (*A*) of Fig. 4, *i.e.*, it is due to the presence of ammonium bicarbonate and its consequent reaction with ferric chloride.

In curve 2 of Fig. 5 the sludge was diluted, and the diluted sludge treated with a wide range of coagulant dosages. This only made the first break more pronounced on curve 2 of Fig. 5.

A portion of this sludge was well elutriated, allowed to settle 2½ hours, and the elutriate decanted. The results of this experiment are shown by curve 3 of Fig. 5. Here the "irregular series" effect is very apparent. That the reversal of charge does not bring the filtration rates back to zero may be due to coagulant overdoses, either affecting only those colloids having a certain high degree of adsorbability, or only those colloids containing amino acids. Experiments similar to this were conducted on a number of elutriated digested sludges with similar results.

A portion of the elutriated sludge of the preceding experiment was treated with ammonium carbonate-carbamate in order to reproduce approximately the original AAN content of the unelutriated sludge. Curve 4 of Fig. 5 is practically in the same coordinate position as curves 1 and 2, and of similar shape.

In their investigations relating to the digestion of garbage with sewage sludge, Keefer and Kratz [21] produced some digested sludges relatively rich in ammonium bicarbonate. A sample of one of these highly ammoniacal sludges was made the subject of the investigations shown in curves 1, 2 and 3 of Fig. 6. These results are clear evidence of the effect of ammoniacal compounds in sludge liquors on ferric chloride consumption. The digested garbage and sewage sludge contained practically double the amount of AAN as the sludges of Figs. 2 and 4 and required almost double the amount of coagulant for complete floccula-

tion and precipitation. At the very best, filtration rates were sluggish, due to the gelatinous nature of the precipitate formed by the reaction of ferric chloride with ammonium bicarbonate and other ammoniacal compounds.

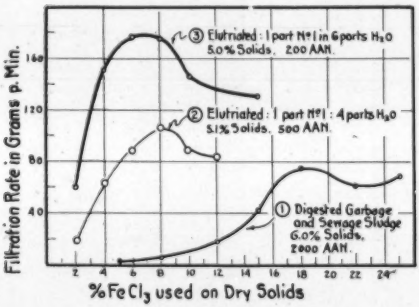


FIG. 6.—Effect of elutriation of digested garbage and sewage sludge.

Because of the high ammoniacal content of this sludge, relatively copious amounts of elutriating water were necessary to remove AAN. The results of such elutriations are shown by curves 2 and 3 of Fig. 6. The elutriated sludge of curve 3 required only slightly more than 2 per cent $FeCl_3$, based on dry solids, to produce the same filtration rate that resulted from adding 18 per cent $FeCl_3$ to the original unelutriated sludge, and at one-third $FeCl_3$ addition, the maximum of filtration rates was more than double the maximum of filtration rate obtained on the unelutriated sludge.

Results With Raw and Activated Sludges

As Baltimore raw sludge contains considerably less soluble ammoniacal compounds than the same sludge after digestion, it was assumed that much less ferric chloride would be used for the coagulation of raw sludge than was used in the preceding tests.

Curve 1 of Fig. 7 clearly shows this assumption to be true. The lower filtration rates with raw sludge are probably due to their higher content of amino and fatty acids. Notwithstanding this fact, the amounts of ferric chloride necessary for obtaining maximum filtration rates on Baltimore raw sludges are directly related to the soluble AAN present in such sludges. Furthermore, elutriated raw sludges show the same increase in filtrability with low ferric chloride dosages that is common to elutriated digested sludges.

Due to the fact that the AAN of the raw sludge was comparatively low (200 p.p.m.) there should not be much difference in filtration and ferric chloride consumption by elutriating such a sludge in two or three volumes of water. The small differences obtained are shown by a comparison of curves 2 and 3 of Fig. 7.

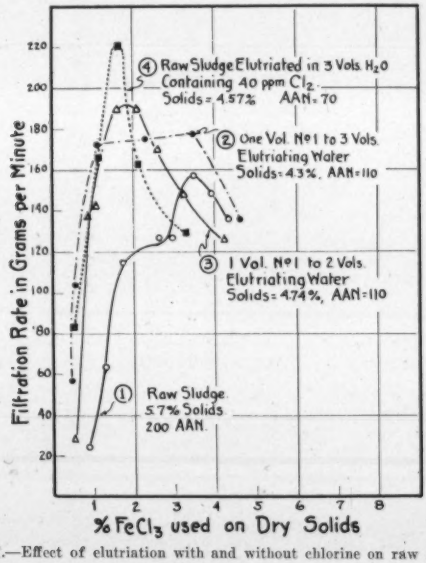

Filtration Rate in Grams per Minute
% $FeCl_3$ used on Dry Solids
④ Raw Sludge Elutriated in 3 Vols. H_2O Containing 40 ppm Cl_2 Solids = 4.57% AAN = 70
② One Vol. No 1 to 3 Vols. Elutriating Water Solids = 4.3%, AAN = 110
③ 1 Vol. No 1 to 2 Vols. Elutriating Water Solids = 4.74%, AAN = 110
① Raw Sludge 5.7% Solids 200 AAN

FIG. 7.—Effect of elutriation with and without chlorine on raw sludge.

In order to aid elutriation chemically the raw sludge used in the above experiments was elutriated with 3 volumes of tap water containing 40 p.p.m. chlorine. Remarkable filtration rates at low coagulant dosages were obtained, as shown on curve 4 of Fig. 7.

Waste activated sludge obtained from Hagerstown, Md., was used for the next experiments. This sludge, like most activated sludges, was rich in biological flocculi and comparatively low in solids and AAN. Nevertheless, it showed the effect of elutriation by Baltimore tap water, free from ammoniacal compounds and nitrates. The results are presented in curves 1 and 2 of Fig. 8.

In order to study the treatment of activated sludge and mixtures of activated and raw sludges, Kratz, Bushman and the writer produced

activated sludge at the Baltimore Sewage Works by seeding Baltimore sewage with sludge from Hagerstown. An experimental aetivation cell was built for the purpose.

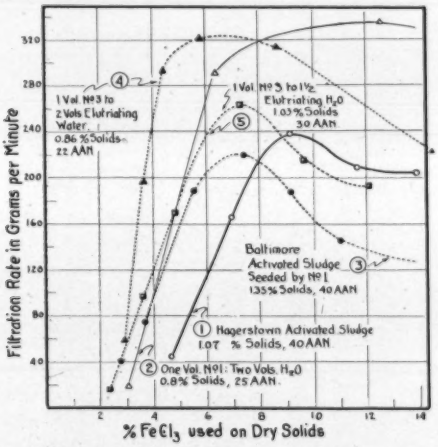


FIG. 8.—Effect of elutriation on activated sludges.

Elutriation experiments on this sludge are shown in curves 3, 4 and 5 of Fig. 8.

The elutriates from the Hagerstown and Baltimore activated sludges were perfectly clear and sparkling and free of colloids.

As raw sludge remains in the preliminary settling tanks five or six days at Baltimore, it shows a greater AAN content in summer than in winter. Winter sludge samples showed approximately 150 p.p.m. AAN, while samples taken in August showed as high as 450 p.p.m. AAN.

A sample of sludge was taken from the preliminary settling tanks at Baltimore during the summer. It contained more AAN than the raw sludge shown in Fig. 7, and consequently it required more ferric chloride for complete flocculation, as shown by curve 1 of Fig. 9.

By mixing this raw sludge with activated sludge, the results shown in curve 2 of Fig. 9, were obtained. The better flocculation values obtained with this mixture were undoubtedly due to the AAN reduction obtained by mixing an activated sludge of 3.0 per cent solids and 55 p.p.m. AAN content with a raw sludge having practically 6 per cent solids and 340 p.p.m. AAN.

Very remarkable filtration rates with low ferric chloride consumption had been obtained by Kratz, Bushman and the writer, by greatly diluting (20 or more to 1) Baltimore raw sludge with sewage and some

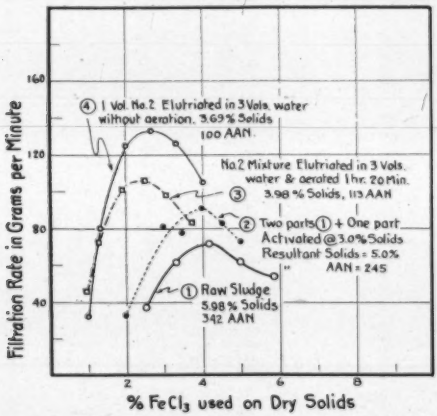

Filtration Rate in Grams per Minute
160
120
80
40
2
4
6
8
% FeCl₃ used on Dry Solids
④ 1 Vol. No.2 Elutriated in 3 Vols. water without aeration, 3.69% Solids 100 AAN
No.2 Mixture Elutriated in 3 Vols. water & aerated 1 hr. 20 Min.
③ 3.98% Solids, 113 AAN
② Two parts ① + One part Activated @ 3.0% Solids Resultant Solids = 5.0% AAN = 245
① Raw Sludge 5.98% Solids 342 AAN

FIG. 9.—Effect of elutriation on mixture of raw and activated sludges.

activated sludge, aerating for some hours and allowing the solids to settle. A further test was made using less dilution and aerating only 80 minutes. The results are shown by curve 3 of Fig. 9. Some improvement was noted, but curve (4) of Fig. 9 shows that elutriation without the short aeration was better.

With Baltimore raw sludges that are but one or two hours old, the AAN content is less than 100 p.p.m. and very low dosages of ferric chloride produce excellent filtration rates. However, the older such raw sludges become, the more difficult they are to treat with ferric chloride. This is undoubtedly due to the rapid increase in amino acids and amino-ammonium compounds.

A widely distributed amino acid, glutamic acid, was added with a small amount of ammonium carbonate to an elutriated sludge (curve *E*, Fig. 4) and allowed to stand for 48 hours. Although the resulting AAN of this sludge was less than that of the ammoniated sludge shown in Fig. 4, the filtration rates obtained were similar to those shown in curve 1 of Fig. 9.

Adding unelutriated digested sludge to an unelutriated raw sludge which is several days old does not improve filtration rates nor lessen

ferric chloride consumption. Ferric chloride added to an unelutriated digested sludge causes considerable foaming due to liberation of CO_2. However, if 1 volume of an unelutriated digested sludge is added to 1 volume of Baltimore raw sludge and the mixture stirred for several minutes, and then ferric chloride is added, and the mixture again stirred, the usual foaming does not occur. In all probability this is due to the fact that the CO_2 present in the digested sludge combines with the amino acids of the raw sludge to form carbamino acid, or the ammonium salt of this acid. The ferric salt of carbamino acid is water soluble.

If the digested sludge is elutriated and then added to the unelutriated raw sludge in the same proportions and ferric chloride is added, a material increase in filtration rates is obtained, with lower ferric chloride demand. This is undoubtedly due to the removal of ammonium bicarbonate from the digested sludge by elutriation.

Discussion

Studies at Baltimore indicate that well-digested sludges have an active hydrogen ion. Notwithstanding the fact that digested sludges were elutriated with tap water having a pH of 8.2 and sometimes 8.4, the pH of the successively elutriated sludges gradually decreased. An actual separation of ions by adsorption is impossible. "The observed adsorption is always a compromise between the tendency of the more strongly adsorbable ion to go to the interface, and of the more weakly adsorbable one to remain in solution. The more strongly adsorbable ion will drag the other in part to the interface; the more weakly adsorbable ion will, on the contrary, partly hold back the more strongly adsorbable in solution."[22] Undoubtedly the hydrogen ion is the most strongly adsorbed in raw and digested sludges.

Investigations made over two years ago at Baltimore showed that if the coarser, visible particles of digested sludges were separated from the sludge liquor by centrifuging or prolonged sedimentation, the pH of the clear liquor was found to be as high as 8.8. Yet if the sludge particles, obtained from these liquors, were placed in a LaMotte cell containing boiled, distilled water having a pH of 6.9 or 7.0, the pH of the resulting liquid was found to be as low as 6.5. This indicated an active hydrogen ion in well digested sludge particles. To test this in another manner, the distilled water was saturated with carbon dioxide in order to make the pH of this water 5.7. Using this in a LaMotte cell with the digested sludge particles resulted in a pH of 5.9 and 6.0. This indicated an exchange adsorption, wherein hydrogen ions of $H^+ \cdot CO_3^-$ were adsorbed in exchange for weaker, neutralizing ions held by the sludge solids. In the cases investigated, the exchanged ions were, in all probability, those of ammoniacal nature.

In these cases and in the elutriation and flocculation tests, the suspended solids in Baltimore sewage sludges act remarkably like capillary adsorbents.

The extensive field tests made by Keefer and Cromwell [23] on dewatering various sludges with two types of continuous suction filters at the Baltimore Sewage Works in 1931–32 indicated that digested sludges showed little uniformity in their sensitivity to ferric chloride treatment. This was notwithstanding the fact that the digested sludges investigated came from a heated digestion tank with a temperature kept practically constant throughout the year. The sludges treated and filtered during winter months required less ferric chloride for efficient dewatering than did digested sludges treated during the hotter summer months.

Laboratory investigations of various sludge samples led to the conclusions that the main factor influencing the high and erratic ferric chloride consumptions was ammonia and its derivatives resulting from the decay and putrefaction of sludge solids.

It was thought that Baltimore raw sludges decomposed further in summer and contained more ammonia than in winter.

Laboratory tests showed that winter sludges contained about 150 p.p.m. AAN and summer sludges up to 450 p.p.m. Digested sludges sampled simultaneously showed an increase from about 650 p.p.m. AAN in winter to about 1,000 p.p.m. in summer. These digested sludges became progressively more difficult to dewater as summer weather approached.

AAN in laboratory samples of raw sludge invariably increased from day to day when the samples were held at normal room temperatures, and digested sludge samples, kept in the same manner in open containers, invariably showed a loss of ammonia due to evaporation. The ferric chloride demand of raw sludge increased in proportion to the ammoniacal nitrogen increase. Although the digested sludge kept in open containers did not rapidly lose ammonia by evaporation, the gradual decrease reflected itself in the ferric chloride consumption and filtration rates.

Decomposing sewage sludge contains ammonium bicarbonate as an important soluble end product of protein decomposition. Raw sludges contain proteins from organic food residues and bacteria, together with the ammonia derivatives resulting from the natural hydrolysis of proteins. The biuret test showed the presence of proteins in raw and well digested sludges at Baltimore. The test showed a more intense color reaction with raw sludges. Likewise the clear liquor obtained from diluting raw and digested sludges with distilled water reacted positively to the ninhydrin test, indicating the presence of amino-acid groups. The liquors of raw sludges showed a deeper color than did those of digested sludges.

This is mentioned to show that the determination of the optimum of precipitation is but another method of determining the approximate isoelectric point of colloids. The pH value at which a maximum filtration rate was always obtained on elutriated sludge, was approximately 4.7.

The isoelectric point of protein colloids is pH 4.7. Kruyt [8] connects this and the protein wall-charge with the amino-acid linkages present in protein colloids. If hydrochloric acid is added to the water surrounding such colloids so that the pH is less than 4.7, the amino-acid linkages in the wall $R \cdot NH_2 \cdot COOH$ ionize to $(HOOC \cdot R \cdot NH_3)^+$ and Cl^-. When the pH is above 4.7, due to the presence of alkaline sodium or ammonium compounds in the surrounding water, the amino-acid linkages ionize to $(R \cdot NH_2 \cdot COO)^-$ and NH_4^+. In the former case, the protein colloid has a positive wall charge, and in the latter case it has a negative wall charge due to the $(R \cdot NH_2 \cdot COO)^-$ portion remaining in the wall.

As the curves in Figs. 2 and 4 show a reversal and drop in filtration rates at pH values lower than approximately pH 4.7, the writer believes that this is due to a reversal at the wall-charge by excess ferric chloride. Furthermore, the writer believes that the similarity between the isoelectric points of protein colloids and elutriated digested and raw sludges at Baltimore is not accidental. This similarity is, in all probability, due to the presence of amino acids in the solids of such sludges.

In cases where the optimum of flocculation occurs at a higher pH, such as the unelutriated digested sludges and those containing artificially added ammonium carbonate and sodium bicarbonate, the isoelectric point is shifted due to chemical precipitation and flocculation occurring together.

In this connection an examination of the curves of unelutriated and elutriated digested sludges shows that the curves for well-elutriated sludges are of the true parabolic type and similar to adsorption curves.

Both unelutriated and elutriated digested sludges show the typical tendency to become thick and viscous when ferric chloride is first stirred into them. The floc then loses the liberated water and becomes less viscous. This phenomenon is termed "coacervation" (piling up) by Kruyt. Although this coacervation is accompanied by considerable foaming and gas liberation when treating digested sludges with ferric chloride, the foaming is absent after such sludges have been elutriated in two or more volumes of water. The cakes produced by filtering flocculated, elutriated sludges are therefore less porous and more compact than the cakes resulting from filtering flocculated, unelutriated digested sludges.

SUMMARY

1. Sewage solids in domestic sewage sludges at Baltimore, Md., act like capillary adsorbents. They are of a mixed suspensoid and emulsoid nature and, when surrounded by relatively pure water, require little coagulant for producing floccules that are readily dewaterable by suction filtration.

2. The optimum of pH for maximum of filtration rates of raw and elutriated raw and digested sludges at Baltimore, approximates the pH of the isoelectric point of colloids containing protein.

3. The solids of the sludges investigated have an active hydrogen ion and are negatively charged relative to the surrounding liquid. Due to their fermentative and putrefactive nature, they are highly ionogenic. The liquors surrounding such solids become relatively rich in ammoniacal compounds during biological processes of decomposition. Some of these compounds are adsorbed by the colloids and capillary active surfaces present, or by the active hydrogen ions of such colloids and surfaces.

4. These ammoniacal compounds chemically react with ferric coagulants intended for flocculating the colloids present. Therefore, these parallel reactions consume more coagulant than is necessary for the flocculation of the colloids alone.

5. The concentration of the soluble decomposition compounds in the solutions surrounding sludge solids and held by adsorption, can be easily decreased by changing the adsorption equilibrium. The simplest method consists in diluting the sludges with relatively pure water, or water containing active chemicals or exchange adsorbents, allowing the sludges to settle and decanting the supernatant equilibrium liquid. This procedure is termed "elutriation" by the writer.

6. Such elutriation of sludges results in definite savings in coagulant.

7. Simple elutriation, without chemical aids, results in the greatest savings when applied to digested sludges and mixtures of elutriated digested sludges with either raw or activated sludges.

8. The coagulant savings effected by elutriation of sludges containing soluble ammoniacal products are approximately in direct proportion to the amounts of the soluble ammonia-amino compounds removed by elutriation. A 2 to 1 elutriation of Baltimore digested sludges will remove at least 60 per cent of the soluble ammoniacal products from the liquor surrounding such sludges and save about 60 per cent of the ferric chloride necessary to produce a floc that can be dewatered in two or three minutes on a suction filter.

9. The removal of soluble compounds of ammonia and ammonia derivatives from sludges has definite economic advantages because of the

consequent coagulant savings produced. However, any incidental removal of some colloids by simple elutriation shows no economically measurable savings in coagulant.

Application

Under the direction of C. E. Keefer, Principal Assistant Engineer of the Bureau of Sewers, Baltimore, Md., and Herman Kratz, Jr., Chemist at the Baltimore Sewage Works, the practical application of this sludge elutriation process has been undergoing exhaustive field tests. More complete and valuable field data relating to various coagulants, B.O.D. and suspended solids of elutriates, variations of sludge moistures and amino-ammonia nitrogen content of sludges, mixtures of elutriated, digested and raw sludges, etc., will be published by Keefer and Kratz in the next issue of This Journal.

Acknowledgment

The Baltimore Sewage Works, where these investigations were conducted, are under the general supervision of B. L. Crozier, Chief Engineer of the Department of Public Works, G. E. Finck, Sewerage Engineer and C. E. Keefer, Principal Assistant Engineer, with G. K. Armeling, Superintendent, and E. C. Cromwell, Principal Sanitary Chemist.

For encouraging cooperation in the author's investigations appreciation is expressed to C. E. Keefer and to Herman Kratz, Jr., and J. W. Bushman who were associated with the writer in this research. For assistance in investigating chemical deammonification of sludges, credit is due E. C. Cromwell and Paul Smith, and for assistance in checking the accuracy of laboratory amino-ammonia nitrogen determinations, appreciation is expressed to E. C. Cromwell and Henry Weiner.

To L. L. Hedgepeth of the Pennsylvania Salt Manufacturing Co., and L. H. Enslow of the Chlorine Institute, the writer is indebted for an early and continued interest in the sludge deammonification investigations reported here.

For generous cooperation in supplying coagulants and deammonification reagents for laboratory and field investigations, acknowledgment is due the Pennsylvania Salt Manufacturing Company, The Grasselli Chemical Company, E. I. du Pont de Nemours and Company, and the Merrimac Chemical Co. For supplying Aloxite tubes for chlorination and sludge activation purposes, appreciation is expressed to The Carborundum Company.

Literature Cited

1. F. W. Mohlman and G. P. Edwards. *Indust. and Eng. Chem.*, **26**, 226 (Feb. 1934).
2. *Philosoph. Trans.*, **151**, 183 (1861) and *Liebigs Annalen*, **121**, 1 (1862).

3. E. W. Washburn and E. B. Millard. *Jour. Amer. Chem. Soc.*, **37**, 694 (1915).
4. Kruyt. "Colloids," 2nd Edition (John Wiley & Sons), pages 242 and 247.
5. *Ber. d. deutsch. Chem. Ges.*, **37**, 1745 (1904).
6. Herbert Freundlich. "Colloid and Capillary Chemistry," E. P. Dutton, pages 255, 256. See also, Quincke. *Poggendorf. Annalen*, **113**, 513 (1861). Perrin. *Jour. Chim. Phys.*, **2**, 601 (1904). McTaggart. *Phil. Mag.* (6) **27**, 297 (1914), **28**, 367 (1914).
7. Nernst. *Zeitschr. f. physik. Chem.*, **9**, 137 (1892). Haber. *Annal. d. Physik* (4), **26**, 927 (1908). Michaelis. "Dynamik der Oberflaechen" (Dresden), 1909 Edition, p. 49, etc.
8. Kruyt. "Colloids," Chapter on Protein Sols, pages 205 to 218.
9. *Jour. Physique* (4) **9**, 457 (1910).
10. H. R. Kruyt. *Proc. Roy. Acad. Amsterdam*, **17**, 615 (1914); **19**, 1021 (1917). *Kolloid. Zeitschr.*, **22**, 81 (1918). H. Freundlich and G. Ettisch. *Zeitschr. f. physik. Chem.*, **116**, 401 (1925). F. Powis, *Idem*, **89**, 91 (1915).
11. H. Freundlich. "Colloid and Capillary Chemistry," p. 642.
12. Freundlich and Neumann. *Zeitschr. f. physik. Chem.*, **67**, 538 (1909).
13. Freundlich and Neumann. *Loc. cit.* Linder and Picton. *Jour. Chem. Soc.*, **87**, 1908 (1905). Whitney and Ober. *Zeitschr. f. physik. Chem.*, **39**, 630 (1902). Fajans and von Beckerath. *Zeitschr. f. physik. Chem.*, **97**, 478 (1921).
14. Rona and Michaelis. *Biochem. Zeitschr.*, **94**, 250 (1919).
15. Kruyt. "Colloids," p. 34.
16. Kruyt. "Colloids," p. 74, 75.
17. Brossa and Freundlich. *Zeitschr. f. physik. Chem.*, **89**, 306 (1915). Buxton and Teague. *Idem*, **57**, 64 and 76 (1907).
18. Henriques and Sørensen. *Zeitschr. f. physiolog. Chem.*, **64**, 120 (1907). Northrop. *Jour. Gen. Physiol.*, **9**, 767 (1926).
19. Hawk and Bergeim. "Practical Physiological Chemistry," 10th Edition, Blakiston, p. 826.
20. Kruyt. "Colloids," p. 89, 90.
21. Keefer and Kratz. THIS JOURNAL, **6**, 14 (Jan. 1934).
22. Herbert Freundlich. "Colloid and Capillary Chemistry," p. 204, 212.
23. Keefer and Cromwell. THIS JOURNAL, IV, **6**, 930 (Nov. 1932).

TENDENCIES IN STANDARDS OF RIVER AND LAKE CLEANLINESS *

By H. W. Streeter

Sanitary Engineer, U. S. Public Health Service
Third and Kilgour Sts., Cincinnati, Ohio

During recent years, a strong trend has developed throughout the entire field of public health and sanitation toward the formulation of standards, both in respect to administrative practice and in relation to methods of technical control. In public health administration, committees thus have been endeavoring to set up standards of organization, budgeting, disease reporting and efficiency rating. In general sanitation we find numerous examples of a similar tendency, such as the formulation of standards for milk control, for housing and air conditioning, for the sanitation of shellfish areas and for the quality of public drinking water supplies.

In connection with the general problem of waterways sanitation, the question of standards has occupied the thought of various authorities for many years past. In Great Britain its consideration began as early as 1865, when the first of several legislative Acts was passed to permit local authorities to combine to protect water-courses from pollution by sewage. In 1875 these several Acts were replaced by the Public Health Act, which was followed by the River Pollution Prevention Acts of 1876 and 1893. Under the former the well-known Mersey and Ribble and West Riding Rivers Boards were organized. In 1898 the second British Royal Commission on Sewage Disposal was appointed and the subsequent reports of various investigations carried out by this Commission have become part of the classic literature of sewage disposal and river sanitation.

Although the congestion of industrial population in Great Britain, together with the smallness and shortness of rivers in that country, caused attention to be directed to stream pollution at a somewhat earlier period than in most other countries, the situation in the northeastern section of the United States caused the Massachusetts Board of Health to institute in 1872 a study of sewage disposal and rivers pollution in that State. This study led to the notable series of investigations at the Lawrence Experiment Station, with which the names of such pioneer leaders as Drown, Sedgwick, Mills, Fuller, Hazen, Phelps, Clark and

* Published by Permission of the Surgeon General, U. S. P. H. S., and Courtesy of Illinois Association of Sanitary District Trustees, Gus Radebaugh, Urbana, Ill., *Secretary*. Presented at Eleventh Annual Convention, Waukegan, Ill., June 13, 1934.

others have been indelibly associated. To these men we owe much of the progress which has been made in this country in water and sewage sanitation during the past 30 or 40 years.

The earlier concepts relative to standards of waterways pollution were shaped very materially by the conditions prevailing both in the British Isles and in New England at that time. In both instances the safety of public water supplies was little involved in the question, as these supplies were derived then, as now, very largely from upland sources located in practically uninhabited drainage areas. The major problem to be met was prevention of the gross degradation of streams which was leading to widespread conditions of nuisance and menace to fish life in numerous important rivers of those areas.

From an exhaustive series of investigations, described in nine separate reports with appendices, the British Royal Commission formulated two sets of standards. One dealt with limiting specifications for the composition of various trade waste effluents including those of coal washing, tin, lead and zinc mining, paper making, brewing, oil distillation, wool scouring and tanning. The other was concerned with the quality of sewage effluents, its more significant provisions being, in brief, that an effluent should not contain more than 30 p.p.m. of suspended matter and should have a 5-day B.O.D. (at 65° F.) not exceeding 20 p.p.m. With various degrees of dilution in the receiving watercourse, ranging from 150 to over 500 volumes of water, this requirement was modified so as to permit as high as 150 p.p.m. of suspended matter in the effluent with dilutions up to 500 volumes.

As the basis of this standard, the Commission formulated a working rule derived from an extensive survey of actual conditions, that the 5-day B.O.D. of a stream water polluted by a sewage effluent should not exceed 4 p.p.m. in order to maintain satisfactory conditions in the stream at a mean summer temperature of 65° F. and under dry-weather flow conditions. In formulating these requirements, the Commission was influenced very materially by a general dictum, enunciated in 1878, that no river in England is long enough to purify itself completely.

In the United States, the first systematic effort to formulate a standard of pollution for rivers was that of Dr. Hering, who in 1887, in reviewing evidence concerning the necessary dilution required for Chicago sewage in the Drainage Canal, concluded that the dilution provided should be at least 150 to 200 cubic feet of minimum stream flow per minute, for each 1,000 persons discharging sewage into the stream. This led to the adoption of a minimum dilution of 3.3 cubic feet per second per 1,000 population.

Shortly after the formulation of the Hering dilution standard Stearns, in a report to the Massachusetts Board of Health issued in

1890, introduced the custom of estimating the amount of various constituents added to sewage by each inhabitant daily and then estimating what these constituents would be in the stream with dilutions ordinarily found in streams of varying degrees of pollution. Although no definite conclusion was drawn, he stated that the debatable limit of dilution would fall somewhere between 2.5 and 7.0 cubic feet per second per 1,000 population. In his Ohio report in 1898, Hazen introduced the qualification that in sluggish streams, or in streams already somewhat polluted, the proper dilution might be increased to 6.8 or 10 cubic feet per second per 1,000 persons. In 1902, Goodnough concluded from his surveys in Massachusetts that objectionable conditions were found in all cases where the dilution was less than 3.5 second-feet per 1,000 persons, but were not likely to be objectionable where the dilution exceeded about 6 second-feet.

As previously noted, these various dilution ratio standards, as well as that which the British Royal Commission formulated for sewage effluents, were based very largely on observations made in relatively small and short streams, where natural purification was not a very powerful influence, and they were concerned primarily with the prevention of conditions which would be termed as offensive, rather than with maintaining the safety of public water supplies, which was not materially involved in these situations.

During the past twenty-five years or thereabouts, the public health aspects of river and lake pollution have been receiving more attention, both in this country and abroad, as the result of a growing public consciousness of this phase of the problem. At the present writing, a fairly clear distinction is being made by sanitary authorities between water pollution directly or indirectly affecting the public health and that which is concerned primarily with economic rather than health values, though in some cases the two interests are so intimately related that a sharp line of distinction can hardly be drawn between them. On this basis we may attempt a rough classification of water pollution problems as they now exist in this country and then consider briefly the present trend of thought relative to the standards of pollution under each respective class.

The main items of such a classification might be stated somewhat as follows:

I. Pollution not affecting directly the public health.

A. That which gives rise to conditions commonly included under the general term "nuisance," or which, though not causing actual "nuisance," may tend to damage the value of bordering property for residential, agricultural or recreational uses.

B. That which affects the maintenance of fish life in streams and lakes, and the use of such water for recreational purposes.

C. That which may cause tastes, odors, or other undesirable qualities in public water supplies.

II. Pollution affecting the public health.

A. Excessive pollution of sources of water supply, either by sewage or by toxic industrial wastes.

B. Pollution of edible shellfish growing areas by sewage and industrial wastes.

C. Pollution of water areas used for bathing purposes.

Let us now consider some of the present tendencies in reference to standards of pollution under these headings.

Standards of Pollution Not Directly Affecting Public Health Interests

The general tendency in fixing limits of pollution of waterways not used as sources of public water supply, or for shellfish culture, or for bathing purposes, has been in this country, at least, to specify a minimum permissible dissolved oxygen content of such waters under summer, low-water conditions, or to set some requirement as to a favorable balance between oxygen demand and oxygen supply.

For "nuisance" prevention, the limiting minimum dissolved oxygen content has been variously stated, ranging from as low as 25 or 35 per cent to as high as 70 per cent of the oxygen saturation value. In a recent report on the disposal of sewage in the Potomac River, Crohurst * notes that certain investigations in the Thames River below London and in the Delaware River at Philadelphia, have indicated that under conditions there existing, the dissolved oxygen in the supernatant stream could be as low as 10 or 20 per cent without causing odors in the vicinity of the point of low oxygen content. On the other hand, a minimum D.O. as high as 70 per cent of saturation was recommended by Black and Phelps † as being desirable for New York Harbor, though other observers suggested later that this figure might be lowered safely to 25 or 35 per cent, provided that sludge deposits could be kept under control. In the recent report of the Tri-State Treaty Commission of New York, New Jersey and Connecticut, on measures for abating pollution of the harbor and coastal waters of the metropolitan area, the minimum dissolved oxygen recommended for Class "B" areas, not used for bathing or shellfish culture, has been 30 per cent of saturation, with the

* "Disposal of Sewage in the Potomac River," U. S. 72nd Congress, 2nd Session, Senate Document No. 172.

† "Discharge of Sewage Into New York Harbor," Black, W. M., and Phelps, E. B. Report to New York City Board of Estimate and Apportionment. 1911.

added requirement that not less than 10 per cent of the suspended solids should be removed from the wastes discharged into these areas.

In several recent cases, as in that of the Illinois River, a standard of pollution based on maintaining a positive oxygen "balance" or excess of available oxygen supply over oxygen demand, has been recommended. This viewpoint is somewhat like that underlying the British Royal Commission standard, which as previously noted was based on the principle of maintaining a 5-day B.O.D. in the stream water not exceeding 4 p.p.m., a fairly safe margin for obtaining a positive oxygen balance.

For supporting fish life in streams and lakes, minimum oxygen standards are in general most widely favored in the United States, though the validity of this and other single criteria, has been recently attacked by Hubbs,* an expert in fisheries research, who points out that some conditions deleterious to fish are not reflected either by dissolved oxygen or by oxygen demand values in a stream water. Opinions as to the minimum amount of dissolved oxygen in a natural body of water necessary to support ordinary fish life have varied, some observers placing it as low as 2.5 p.p.m., and others as high as 4.0 p.p.m. Recent practice, however, has favored 3.0 or 4.0 p.p.m. as being desirable, when considered as an average minimum, and the present trend is toward even higher concentrations, where maintaining all normal forms of fish life is involved.

In this connection, Hubbs notes the "minnow test," as used in New York, and the reserve oxygen criterion, in which an excess of dissolved oxygen over oxygen demand amounting to upwards of 3 p.p.m. in specified. Although he regards the "minnow test" as unreliable, because of the variability of different species of minnows in their viability, he considers the "reserve oxygen" type of standard as being a step in the right direction, as compared with the simple minimum dissolved oxygen requirement. He points out, however, that the application of standards of this kind on the basis of average observations may be misleading, citing as an example an instance in which owing to algae growths, the observed dissolved oxygen content during sunny daylight hours ran as high as 200 per cent saturation, but during the night and especially in the early morning, it became practically exhausted. Under such conditions numerous fish could be killed during a comparatively short period of oxygen depletion. Sewage sludge deposits are considered by Hubbs as being particularly detrimental to fish life, as they interfere with the normal spawning process.

The presence of undesirable tastes and odors in water supplies and

* Sewage Treatment and Fish Life." C. L. Hubbs, THIS JOURNAL, 5, 1033–40, 1933.

means for correcting them have engaged the attention of sanitary chemists and biologists for many years. More recently, this problem has become one of primary importance, owing to the extreme sensitiveness of the consuming public to the aesthetic properties of their drinking water and to the increasing difficulties experienced in removing tastes and odors from water supplies derived from highly polluted sources. In some instances, as where phenols and cresols are present, treatment may only serve to intensify these disagreeable effects. In others, as where the products of organic decay are present, the resulting tastes and especially odors may be very difficult to remove once they have become established.

Although no definite standards have been adopted in these cases, a systematic effort is being made in several States to eliminate known sources of pollution by taste-producing substances. Phenol-bearing wastes have been a special point of attack in this connection, as it is now recognized that the only certain way to prevent tastes originating in wastes of this character is to divert them entirely from streams and lakes used as sources of water supply. A basis for more accurate measurement of tastes and odors in water supplies has been recently established through the work of Spaulding and Baylis in Illinois and that of Fair and his associates at Harvard University. With such improved tests now available, a more precise definition of taste and odor standards and their application is possible.

In some sections of the United States, pollution of sources of public water supply by certain mineral substances has an important bearing on the general suitability of these supplies for domestic and industrial use, entirely aside from its possible effects on the public health. In the oil field areas of the southwestern States, for example, the increasing contamination of both surface and ground waters by sodium chloride, or common salt, originating in brines associated with oil deposits, has given rise to a problem of growing seriousness as affecting the general suitability of water supplies derived from these sources, as no practicable method of water treatment can remove this constituent. In some of the western States, pollution of water supplies by sodium salts and other hardness-bearing minerals has resulted in another problem of similar import. In the coal mining regions of Pennsylvania and West Virginia, the leaching of acid mine wastes into surface streams has impaired the suitability of both industrial and domestic water supplies in these sections. These are only a few of numerous instances of mineral pollution largely due to the intensive operation of certain industries, which if not curbed may conceivably result ultimately in making some portions of these areas almost uninhabitable by large aggregations of population.

In promulgating a revised official standard of quality for drinking water supplies furnished to the traveling public by the interstate carriers, the U. S. Treasury Department, acting through an advisory board of the Public Health Service, included in the standard a specification as to the limiting permissible concentrations of certain mineral salts producing undesirable tastes and hardness in such waters. Among these salts, chlorides and sulphates are limited each to 250 p.p.m., magnesium to 100 p.p.m., and carbonates of sodium and potassium to 50 p.p.m. It is of interest to note in this connection that an important city in the south-western part of the United States recently was obliged to discard considering a nearby surface source of water supply, though ample in quantity, because the chloride content of water obtainable from this source was found to be in excess of the limit fixed by the Treasury Department Standard.

Standards of Pollution Affecting Public Health

It has been previously noted in this paper that the three main effects of river and lake pollution in the United States related to the public health, are those which have to do with the safety of (1) public water supplies, (2) shellfish growing areas, and (3) public bathing places. Before taking up the most important of these, which is, of course, the effect on public water supplies, let us consider the two others in the order named.

In the year 1925, following outbreaks of typhoid fever in various cities of the United States in 1924, definitely traced to infections received from eating contaminated oysters, the Federal Government through the Public Health Service, established in co-operation with the States a system for controlling the sanitation of the shellfish industry, including the water areas used for growing purposes. In this connection, a tentative standard was suggested for limiting bacterial pollution of the waters in which shellfish were grown, this standard providing that the waters should ordinarily not show the presence of *B. coli* in 1 c.c. amounts, tests being made in 10, 1.0 and 0.1 c.c. volumes according to the Standard Methods of the American Public Health Association. A modification of this standard, which in effect limited the *B. coli* index of these waters to 10 per 100 c.c. was later suggested, permitting the waters to show *B. coli* in 50 per cent or less of the 1 c.c. amounts tested. The effect of this modification was to fix a maximum *B. coli* index of 50 to 100 c.c. for ruling out waters from market shellfish growing. This standard is now applied in a number of States co-operating in shellfish sanitation.

Under the leadership of Gage, a joint committee of the American Public Health Association and the conference of State Sanitary Engi-

neers issued in 1926 and 1928 reports suggesting comprehensive standards for the sanitation of bathing pools. In 1932, the committee, under the chairmanship of Scott, extended the scope of its activities to considering standards for outdoor bathing places, including those located in natural bodies of water. In its 1932 report, the committee notes existing practice in certain States relative to bacterial standards of pollution for natural waters used for bathing purposes.

According to their report, the proposed standard in California limits the *B. coli* index of these waters to 1,000 per 100 c.c. In New York City a limiting standard of 3,000 per 100 c.c. is used. From a study of Connecticut waters, Winslow and Moxon have suggested that possibly an average of not over 100 *B. coli* per 100 c.c. with a maximum not over 1,000, might be a reasonable figure for such a standard. The Connecticut State Department of Health recently completed an extensive survey of shore bathing waters in that State, from which the following classification of these waters was made on the basis of their average *B. coli* content:

Class	Average *B. coli* Index per 100 c.c.	Percentage of Shore Mileage
A	0–50	64.0
B	51–500	18.6
C	501–1000	10.2
D	Over 1000	7.2

Class A was considered good; Class D was very poor, with the two intermediate classes ranging from doubtful to poor. It is of interest to note that exact correlation of the analysis and sanitary survey was in 62 per cent of the total areas and that an additional 37 per cent showed a difference of only one class, leaving only one per cent of the total area where the analytical results did not check up with the sanitary survey data.

If the Connecticut classification were applied to the other standards above noted, the New York City standard would admit all four classes from A to D; the California standard would admit all but Class D, and the Winslow-Moxon, Classes A and B. The U. S. Public Health Service's tentative shellfish water standard of 50 *B. coli* index per 100 c.c. would admit Class A only. The committee recommends adoption of the Connecticut classification as the basis of further study, which it feels should be given especially to defining the proper status of Classes B and C.

The question of pollution standards for water areas used for recreational purposes has been closely related to that of bathing water standards. The Tri-State Pollution Commission, previously mentioned in this paper, has dealt with this question by including recreational water

areas in Class A in its scheme of classifying those of the Metropolitan district surrounding New York City. For this class, all sewage discharged into such waters must be treated so as to remove all floating solids and at least 60 per cent of the suspended matter, and to effect a reduction in *B. coli* organisms consistent with the requirement for Class A waters in the Connecticut scheme (*i.e.*, having a *B. coli* index not exceeding 50 per 100 c.c.).

It thus appears that for the better class of water areas devoted to shellfish culture, to public bathing, or to recreational uses, a distinct tendency now exists to work toward a bacterial standard represented by a limiting *B. coli* index approximating 50 per 100 c.c. It is of interest to note that this single standard has been reached by separate agencies working on three different kinds of water-use problems. It will be shown presently that this standard also practically coincides with what has been determined as the upper limit of bacterial pollution of raw waters subjected to chlorination alone, for public water supplies, which will be the next and final aspect of this subject to be considered here.

The history of efforts to formulate standards of pollution for sources of public water supplies is comparatively recent, extending back only to the year 1914, when the International Joint Commission of Canada and the United States adopted as a standard of this kind the rule that the yearly average *B. coli* index of sources of water supply located in the International Boundary Waters between the two countries should not exceed 500 per 100 c.c. This standard was based on the joint opinion of a board of expert sanitary engineers employed by the Commission, who formulated it on the assumption that all public water supplies derived from the Boundary Waters should be purified to an extent such that their *B. coli* content would not exceed the limit imposed by the original Treasury Department official water standard (*i.e.*, a *B. coli* index of 2 per 100 c.c.).

Shortly after the International Joint Commission standard was recommended, the U. S. Public Health Service, in connection with its investigation of stream and lake pollution, began a comprehensive field and experimental study of the efficiency and limitations of current water purification systems under conditions of practical operation, with a view to establishing, if possible, an empirical basis of formulating standards for various general types of raw water sources, combinations of water treatment and desired qualities of final effluent, the latter being in anticipation of further revision of drinking water standards, such as that of the Treasury Department, which might be made from time to time. During the progress of this study, the Treasury Department water standard was revised (in 1925) so as to provide, in effect, that the average *B. coli* index of drinking water served by the interstate car-

riers should not exceed 1.0 per 100 c.c., with a permissible range of variation up to 6.0 per 100 c.c. in not more than 5 per cent of the samples examined.

The results of this study, which have been published from time to time, have indicated that for the average efficient modern water filtration plant of the usual rapid sand type, with postchlorination included, the maximum raw water *B. coli* index yielding a final effluent conforming to the revised Treasury Department *B. coli* standard will approximate 5,000 per 100 c.c., as a round number, for all classes of water sources considered, including the Great Lakes and rivers of the general type found in the great Mississippi basin.

If a single limiting standard of pollution for both river and lake sources of purified water supplies in this general area were to be recommended from the results of the Public Health Service study, a rounded *B. coli* maximum of 5,000 per 100 c.c. expressed in terms of the Phelps index, or a corresponding maximum of about 9,000 per 100 c.c. when expressed in terms of the "most probable number," would appear to be the most rational basis available for such a standard, for the following two reasons: (1) it represents, within the range of expected error, the limiting content of raw water *B. coli* organisms observed, for each group of filtration plants studied, as being consistent with producing final effluents meeting the current Treasury Department drinking water Standard, and (2) it marks approximately the critical average density of raw water pollution above which difficulties in effective treatment and in obtaining palatable and otherwise satisfactory effluents for domestic use have been observed quite consistently as beginning to appear.

In applying a standard of this kind, due account would have to be taken of the fact that the *B. coli* densisty above stated is a limiting *maximum*, rather than a limiting *average*, and that a raw water having a yearly average *B. coli* index of 5,000 or thereabouts might show a considerable excess of *B. coli* content over this amount for a significantly large proportion of the time. For this reason, it might be necessary, in formulating it, to use a working factor of safety, either by scaling down the permissible limit below 5,000, as a yearly average, or by requiring an average quality of final effluent somewhat better than that which is represented by the *B. coli* limit fixed by the present Treasury Department Standard (which, in fact, would have the same effect). On the other hand, it is entirely possible that some form of supplementary water treatment, such as pre-chlorination, preliminary storage, or prolonged sedimentation, might provide a sufficiently ample working margin of safety in individual cases, to cover adequately all ordinary variations in raw water pollution above a yearly average limit expressed by a *B. coli* index of 5,000. Should the matter of adopting a definite

standard of bacterial pollution for sources of purified municipal water supplies become one of primary importance from an official public health standpoint, as is entirely within the range of possibility during the next few years, this question doubtless would receive careful consideration.

Where conditions are such that the only form of water treatment practicable is simple chlorination, the Public Health Service study has indicated that a safe bacterial limit of raw water pollution for all classes of waters considered would be represented by a *B. coli* index approximating 50 per 100 c.c.,* which, it may be noted, is the same as that which has been adopted as the upper limit of pollution of waters used for shellfish-growing and for public bathing.

Before concluding this paper, a few remarks may be added concerning the relation of standards of chemical pollution to the safety of public water supplies. These chemical standards are becoming more important with the growing recognition of the harmful effects which wastes from certain industries are having on the hygienic quality of public water supplies. Although the present Treasury Department water standard fixes a definite limit to the content of certain metals, such as lead and copper, which have been more or less definitely associated with poisonous effects produced on consumers of water containing them, other toxic substances have become matters for serious concern in water supplies during the past few years, since the present Treasury Department standard was promulgated. Among these are phenols and cresols, together with their chlorine derivatives, fluorine and fluorides, barium salts, and also cyanides, which recent British studies have shown to have been responsible for killing many young fish in the River Tees. With the present tendency toward using barium salts in connection with water softening operations, a close watch must be maintained over the use of this chemical, which is known to be toxic to humans in small concentrations. It may be earnestly hoped that action will be taken in the not distant future to define the safe physiological limits of these various toxic substances in public drinking water supplies and to incorporate them into standards which may be adopted for such supplies in the future.

In conclusion, the present situation with reference to standards of

* This rounded figure has been obtained by averaging three separate maxima, 30, 50 and 80 per 100 c.c., derived from three independent series of observations. The first was obtained from experimental observations on the purification of Ohio River water (see Public Works, Dec. 1933, pp. 17–20), and the second and third, from combined performance data for two large groups of municipal filtration plants located, respectively, along the Ohio River and the Great Lakes (see Public Health Reports, April 14, 1933, pp. 377–400; Reprint 1565, p. 20). As all three maxima fall within a common range of expected observational error, their mean is a fairly representative average for all conditions embraced by the combined results.

river and lake pollution may be summed up very briefly as follows. The older standards based on fixed dilution ratios are being superseded by more definite specifications of certain indicators of relative cleanliness such as bacterial content, dissolved oxygen, oxygen demand and known toxic chemical substances. Where the public health is involved, limiting standards of bacterial quality, notably with respect to the density of organisms of the *B. coli* group, are becoming of primary importance, though in some instances limitation of chemically toxic substances is almost equally significant. At the present writing a reasonably firm empirical basis exists for the formulation of working standards of pollution for practically all waterways in this country used as sources of public water supply. This should be done in the near future, so as to coordinate efforts in the various States toward a rational and uniform policy in dealing with this problem, especially in its interstate aspects.

A fairly good basis also now exists for the formulation of tentative standards of pollution for shellfish-growing areas and for natural bodies of water utilized for public bathing. In the latter case, however, caution will be necessary in attempting to meet a bathing water standard in some natural waterways subject to non-controllable pollution by surface drainage water and storm sewage. In some of these instances, at least, the extent of dilution provided would not be sufficient to permit conforming to such a comparatively rigid standard, even if the effect of all of the dry-weather sewage entering the waterway were to be removed through adequate treatment.

Where the public health is not involved, the minimum dissolved oxygen standard appears to be the most simple and readily applied one for general application, though a distinct trend toward oxygen "balance" criteria is apparent. Some question remains as to just where the minimum oxygen level should be placed in specific cases, with a strong tendency to fix it at not lower than 3 or 4 parts per million and at even higher concentrations in some cases. As organic sludge deposits are particularly harmful to fish life and tend to exert a disproportionately heavy oxygen demand on overlying bodies of water, a definite need exists for standards of sewage and industrial wastes treatment adequately stringent to result in practically eliminating these deposits from all streams and lakes.

On the part of the general public, there is a growing consciousness of the dangers and economic losses inherent in the excessive pollution of our waterways by sewage and industrial wastes. With the increase in leisure for all classes of our population and the consequently wider opportunities open to everyone for the enjoyment of streams and lakes for various forms of recreation, this consciousness will become more acute and wide-spread during the next few years. This tendency points

toward more specific and increasingly rigid standards of cleanliness for all public bodies of water, which are the natural heritage of our people. The old cry of "laissez faire" is out of date, in this as in other fields of civilized human life, and the present trend of thought and action carry both a warning and an opportunity to those who are qualified to exert leadership in formulating and putting into effect adequate standards of this kind. As to such standards, it might well be said by way of caution: Let us devise them, try them, revise them and apply them, but also remember that they are but "feeble instruments of human will" and like all such tools, are made to be discarded for better ones when they become worn out.

THE RELATION OF THE pH OF DILUTION WATER TO THE BIOCHEMICAL OXYGEN DEMAND OF VARIOUS WASTES

By J. M. Holderby and Wm. L. Lea

Assistant Sanitary Engineer and Assistant Chemist,

Bureau of Sanitary Engineering, Wisconsin State Board of Health

Biological forms such as are believed to be responsible for the progressive oxidation of the organic matter in sewage and other wastes, the measure of which is commonly termed the biochemical oxygen demand (B.O.D.), are known to be sensitive to changes in the hydrogen-ion concentration of their environment. It is common knowledge that the numbers of bacteria growing in a specific medium can be varied considerably by varying the pH of the medium within rather narrow limits. If the rate of biochemical oxidation of a waste is dependent upon the numbers of bacteria growing therein and upon their relative activity it may be assumed that among other factors, the pH of the dilution water used in the B.O.D. test will have an effect upon the magnitude of the values obtained.

The experimental work reported below was carried out under the direction of Mr. L. F. Warrick, State Sanitary Engineer, Wisconsin State Board of Health, and constitutes part of the research program of the Joint Committee on Biochemical Oxygen Demand Technique of the Great Lakes and Ohio River Boards of Public Health Engineers.[1]

General Procedure

Dilutions of the wastes under examination were made up in duplicate or triplicate with each of eight separate dilution waters the pH of which had been previously adjusted to predetermined values. These dilutions were then incubated for five days at 20° C. ± 1°, after which their residual dissolved oxygen contents were determined. In most cases the pH values of the individual dilutions were determined before and after incubation. Bacterial counts, before and after incubation, were made for a few of the series.

Wastes Examined

Domestic Sewage.—Clarified domestic sewage from the Burke Disposal Plant at Madison was used for all runs. Dilutions used were 1 part of sewage to 39 parts of water. A typical analysis of this sewage is given in Table I.

TABLE I.—*Analysis of Settled Domestic Sewage Results in Parts Per Million*

Total Organic Nitrogen	18	Soluble Solids	756
N. as Free Ammonia	22	Suspended Solids	96
Oxygen Consumed	80	Fixed	36
Total Solids	852	Volatile	60
Fixed	552		
Volatile	300		

Milk Waste.—This waste was ordinarily prepared by diluting 1 part of fresh whole milk with 499 parts of distilled water. For two runs only evaporated milk was used after being diluted to approximately the solids content of whole milk. For the B.O.D. test these synthetic wastes were diluted one part with 39 parts of distilled water.

Pea Waste.—Pea waste was prepared by mashing 100 c.c. of canned peas, diluting the pulp to one liter with distilled water and allowing the whole to settle for 20 minutes. The supernatant liquor was then drawn off and diluted to a total solids content of approximately 1000 p.p.m. Dilutions of 1 part of this waste to 119 parts of water were used for the B.O.D. determinations. A typical analysis of this synthetic waste is given in Table II.

TABLE II.—*Analysis of Prepared Pea Waste Results in Parts Per Million*

Total Organic Nitrogen	28.0	Soluble Solids	754
N. as Free Ammonia	5.6	Suspended Solids	140
Oxygen Consumed	640	Fixed	0
Total Solids	894	Volatile	140
Fixed	92		
Volatile	802		

Packing Plant Waste.—Effluent from the second primary clarification tank treating packing plant wastes at the Burke Disposal Plant in Madison, was used. Mixtures of 1 part of waste to 239 parts of dilution water were employed. A typical analysis of the packing waste is shown in Table III.

TABLE III.—*Analysis of Settled Packing Plant Waste Results in Parts Per Million*

Total Organic Nitrogen	44	Soluble Solids	1770
N. as Free Ammonia	64	Suspended Solids	210
Oxygen Consumed	410	Fixed	42
Total Solids	1980	Volatile	168
Fixed	774		
Volatile	1206		

Dilution Water

Distilled water containing 300 p.p.m. sodium bicarbonate was used as a starting point for all the dilution waters. For each separate run eight one-gallon bottles of this water were adjusted with sodium carbonate or hydrochloric acid to pH values of 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, and 9.0 respectively. This pH range was selected because it covers the range of most natural surface waters. Table IV indicates the quantities of the adjusting reagents necessary in a typical series of dilution waters.

Table IV.—*Amounts of N. Na_2CO_3 or N. HCl Used to Adjust the pH of 3 Liters of 300 p.p.m. Bicarbonate Dilution Water*

Initial pH of dilution water—approx. 7.2

Final pH	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
ml. N. HCl	11.0	7.0	2.3	1.0	0	0	0	0
ml. N. Na_2CO_3	0	0	0	0	1	3	4	5

Each bottle of dilution water was seeded before being used. In most cases seeding was accomplished simply by adding 20 ml. per liter of raw water from Lake Mendota. The presence of plankton forms in the lake water was checked microscopically although no attempt was made to identify or count them. The remainder of the time seeding was accomplished by adding 20 ml. per liter of a mixture of 1 liter of raw lake water with a bacterial suspension made by passing 800 ml. of lake water through 35 ml. of fresh domestic sewage solids held on a filter paper.

Bacterial counts on the seeded dilution waters ranged between 3,500 per ml., and 100,000 per ml. approximately. A close inspection of the original data fails to show any correlation between the degree of seeding and the characteristics of the pH-B.O.D. curves. A concurrent but as yet incomplete study of the influence of the degree of seeding on the magnitude of the B.O.D. results indicates that the seedings used were at all times heavy enough to insure a normal rate of bio-oxidation.

Incubation for five days resulted in an average dissolved oxygen loss in the dilution waters seeded with lake water only of 0.25 p.p.m., with a maximum recorded loss of 0.5 p.p.m. Incubation losses for the waters seeded with the sludge infusion were, average 0.65 p.p.m., and maximum 1.1 p.p.m. It was found that with but few exceptions the pH of the dilution waters did not change during incubation.

Laboratory Procedures

For most of the work dissolved oxygen was determined by the Winkler Method as modified by Theriault and McNamee,[2] for use with samples containing large amounts of organic matter. The Rideal-Stewart modification of the Winkler method as given in standard methods of the American Public Health Association [3] was used for a few of the earlier runs. N/40 sodium thiosulphate was standardized at weekly intervals.

pH determinations were made colorimetrically using the standard indicators. The color standards were kept in sealed tubes.

Dilutions were prepared by siphoning the dilution water into a clean one-liter cylinder containing an appropriate quantity of the waste being used. After thorough mixing with a perforated metal plunger, the contents of the cylinder were siphoned into 250 ml. ground-glass stoppered bottles provided with water seals. The pH values of the dilutions were uniformly the same as those of the diluting waters.

Bacterial counts were made on plain nutrient agar.[3] Plates were incubated at 20° C. ± 1° for 48 hours before counts were made.

Results

Agreement between check determinations of the oxygen depletions was usually within 0.15 ml. of N/40 thiosulphate. Fresh wastes were

Table V.—*Relation of pH of Dilution Water to B.O.D. Summary of Observed Variations*

pH Dilution Water	Domestic Sewage[a]		Pea Waste[b]		Packing Plant Waste[c]		Milk Waste[d]	
	Mean B.O.D. % of Ave. for Series	Average Deviation from Mean	Mean B.O.D. % of Ave. for Series	Average Deviation from Mean	Mean B.O.D. % of Ave. for Series	Average Deviation from Mean	Mean B.O.D. % of Ave. for Series	Average Deviation from Mean
5.5	90.3	8.4	99.0	5.8	86.9	6.3	86.8	10.8
6.0	90.4	9.2	98.9	5.8	91.8	4.2	93.7	8.9
6.5	97.1	3.9	97.5	3.1	102.1	6.9	100.9	4.8
7.0	105.8	4.1	99.1	4.9	103.8	8.4	100.7	8.7
7.5	104.0	6.0	100.8	2.9	102.9	4.6	106.3	5.8
8.0	105.7	4.8	105.5	8.7	102.4	7.5	111.2	6.0
8.5	103.8	4.9	101.6	5.7	106.8	8.0	106.7	7.5
9.0	103.8	5.1	100.5	2.8	104.0	6.1	96.2	11.1

[a] Average of data from 11 independent series.
[b] Average of data from 9 independent series.
[c] Average of data from 15 independent series.
[d] Average of data from 20 independent series.

obtained or prepared for each run and consequently the actual B.O.D. values varied over a considerable range. To reduce the data from all runs to a common basis the following procedure was used. All of the B.O.D. values obtained from a series (from pH 5.5 up to pH 9.0) were totalled and their mean obtained. The value for each pH was then expressed in terms of per cent of this mean. The data shown in Table V are averages of these percentage figures for all the runs on a particular waste, together with the average deviation of the individual

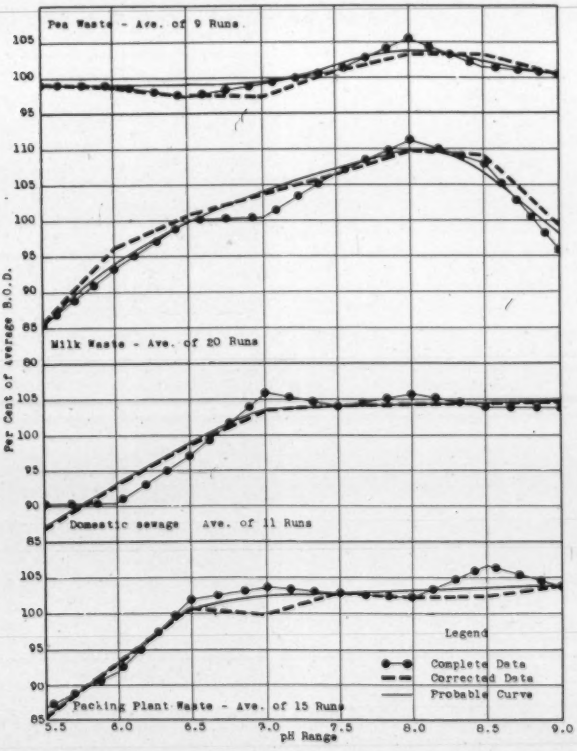

Pea Waste - Ave. of 9 Runs
Milk Waste - Ave. of 20 Runs
Domestic sewage - Ave. of 11 Runs
Packing Plant Waste - Ave. of 15 Runs
Per Cent of Average B.O.D.
pH Range
Legend
Complete Data
Corrected Data
Probable Curve

FIG. 1.—Relative magnitude of 5-day B.O.D. observed with bicarbonate dilution waters having various pH values.

values from the mean of all values obtained at a given pH. These data are presented graphically in Figure 1 by heavy dotted lines. The broken lines in Figure 1 represent the same observations with certain data obviously in error discarded and the solid lines are smooth curves indicating the probable trends.

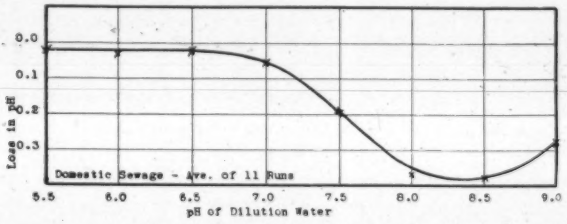


FIG. 2.—Decrease in pH of domestic sewage dilutions after five days incubation.

Table VI and Figure 2 show the average changes upon incubation in the pH of the dilutions of domestic sewage. Similar data for the other wastes did not differ enough from these to warrant their inclusion.

TABLE VI.—*Relation of pH of Diluting Water to B.O.D.*
(Summary of Changes in pH of Incubated Dilutions)
Average of 11 Series with Domestic Sewage

pH of Diluting Water	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Mean Change in pH	0.02	0.03	0.02	0.05	0.19	0.37	0.38	0.28
Maximum Change	0.1	0.1	0.1	0.1	0.4	0.5	0.6	0.4
Minimum Change	0.0	0.0	0.0	0.0	0.1	0.3	0.2	0.1

DISCUSSION

Inspection of Table V and Figure 1 will indicate that below a pH of 6.5 or pH 7.0, depending on the waste, there is a very definite and fairly uniform falling off of the B.O.D. values obtained for all wastes examined except pea waste. For pea waste it appears that in the pH range 5.5 to 7.5 the rate of oxidation is little affected.

Above neutrality we find the curves to be of two general types, (1) flat and approximately horizontal and (2) more or less convex. Curves for domestic sewage and packing waste fall in type (1) while the milk and pea waste curves fall in type (2).

Both of the Type (I) curves have high points at or above neutrality when all the data are plotted, but when certain obviously erroneous

results are discarded, these high points largely disappear. Between pH 7.0 and pH 9.0 the variations in the data for these two wastes are probably not significant.

The data for the milk waste indicate that the increase in the rate of oxidation noted below pH 7.0 continues somewhat less rapidly to about pH 8.0 after which it falls off rather sharply. This same characteristic between pH 7.0 and pH 9.0 is exhibited by the pea waste data though not to the same degree. Discarding erroneous results and smoothing out the curves for these two wastes do take off some of the high points but nevertheless it is believed that the increases in B.O.D. represented by the high points at pH 8.0 in the curves are too great to be due to experimental error. According to these observations, the rates of bio-oxidation for milk and pea wastes are higher at pH 8.0 than either above or below that value.

Explanations for the shapes of the curves in Figure 1 are not obvious. At first it was thought that the generally low rate of oxidation exhibited in the low range and the falling off in the high range could be explained by a decrease in bacterial activity at the two extremes. Against this, however, we have the observations that the rate of oxygen demand for the pea waste is apparently not materially lowered on the acid side and that there is no appreciable falling off at pH 9.0 for the wastes of type (1). Another possibility is that the apparent low oxidation rates are the result of varying lags in the start of the normal oxidation. These two possibilities were studied in a preliminary way by setting up dilutions of the wastes at each pH, determining the initial bacterial count on each series of dilutions and following the oxygen depletion and the bacterial growth each 24 hours for a period of five days. This experiment indicated bacterial growths equally prolific throughout the pH range and lag periods which were also very nearly uniform.

The difference in the characteristics of the two general types of wastes may be due to their carbohydrate contents. Wastes of type (1) are relatively low in sugars, dextrins, etc., while those in type (2) are high in carbohydrates, the milk waste being probably more so than the pea waste. Specific investigation of the influence of sugars in this connection is contemplated.

Such pH changes as noted in the alkaline range of any given series, after five days of incubation, is attributed to the difference in the buffering ability of the various dilution waters against carbonic acid. The dilution waters in this range all contain 300 p.p.m. of sodium bicarbonate but they also contain increasing amounts of sodium carbonate used to adjust the pH. Probably the change in the sodium carbonate to sodium bicarbonate ratio accounts for the varying buffering ability and

the consequent variations in the lowering of the pH values. In the acid range of a series the pH values are adjusted with hydrochloric acid and the solutions are buffered by the residual sodium bicarbonate. Five days incubation produced practically no pH change in the acid range. The pH variations throughout the series (5.5–9.0) were checked experimentally by adding sufficient carbon dioxide solution to a water of pH 9.0 to cause a pH drop of two-tenths. Like amounts of carbon dioxide were then added to the other waters and the losses in pH were checked. The resulting changes correspond with the changes noted in the diluted wastes.

Summary

The experimental work here reported indicates:

1. That domestic sewage, packing plant waste and milk waste may be expected to give higher biochemical oxygen demand values with bicarbonate dilution waters whose reactions are alkaline than with those whose reactions are acid.

2. That pea waste and milk waste have maximum rates of biochemical oxidation with bicarbonate dilution water having an initial pH of 8.0.

3. That within the range of pH 7.0 to pH 9.0 the pH of the bicarbonate dilution water has little or no effect on the biochemical oxygen demand of domestic sewage or packing plant waste.

Acknowledgment

Acknowledgment is made of the assistance rendered by Miss Vera Vincent, Bacteriologist, Wisconsin State Laboratory of Hygiene, in making numerous bacteriological examinations in connection with this study.

Bibliography

1. "Recommended Uniform Procedure for Biochemical Oxygen Demand Determinations. Progress Report—Joint B.O.D. Committee of the Great Lakes and Ohio River Boards of Public Health Engineers." This Journal, **4**, 738 (1932).
2. E. J. Theriault and P. D. McNamee. "Dissolved Oxygen in Presence of Organic Matter, Hypochlorites, and Sulfite Wastes." *J. Ind. & Eng. Chem., Anal. Ed.*, **4**, 59 (1932).
3. "Standard Methods of Water Analysis," *American Public Health Association* (1933).

Sewage Works Operation

TWO YEARS OPERATING EXPERIENCE OF MODERN CHEMICAL-MECHANICAL SEWAGE TREATMENT, DEARBORN, MICHIGAN

By Mark B. Owen

Superintendent of Public Works and Engineering, Dearborn, Michigan

General.—Modern chemical and mechanical treatment of sewage has just passed its second birthday at Dearborn, Michigan. The West Side plant was placed in continuous operation May 1, 1932. Several articles have been published from time to time describing the process, methods of operation and results obtained. Two years of continuous records now available demonstrate how well this type of treatment has served the Dearborn problem, and serve as a basis for intelligent comment on the various phases of plant operation over that period.

A very brief description of sewage treatment in Dearborn is included herewith to assist the reader in a better understanding of the tabulated results. For the purpose of sewage treatment, Dearborn is divided into the East Side and West Side areas and served by the East Side sedimentation plant and the West Side chemical-mechanical plant.

East Side Plant—Sedimentation

Description.—The East Side plant consists of a pumping station, coarse screens, grit chambers, and modified Imhoff tanks. This plant receives sewage from the easterly portion of Dearborn and from a portion of the City of Detroit, as shown in Table I. Sludge is pumped, more or less fresh, from this plant through about 3½ miles of 8-inch main to the West Side plant for final treatment and disposal.

Table I.—*Tributary to East Side Plant*

	Population	Area Acres	Sewage M.G.D.
East Dearborn	40,000	3,700	5
Ford Motor Co.	18,000*		
Detroit	95,000	22,400	10
Total	153,000	26,100	15

* Equivalent permanent population.

Modification of Imhoff Tanks.—The Imhoff tanks were designed and built in 1923 for a sewage flow of about 5.25 m.g.d. at 3.5 hours deten-

tion. Just before the West Side plant was placed in operation some radical changes were made in the Imhoff tanks. Hubbell, Hartgering and Roth, Consulting Engineers, through experiments on a working-scale model of the tanks, determined that the settling efficiency of the tanks could be quite materially increased by making certain changes. Existing adjustable inlet weirs were abandoned and each "flowing-through" channel of each tank was separated by partitions. A valved pipe inlet was provided for each channel and a specially designed baffle placed in front of the inlet to allow proper dissipation of velocity, with reduced turbulence. Electric meter bodies were provided so that the flow to each channel could be closely controlled. Gravity lines from each hopper were run to sludge pumps. These lines were so valved that sludge might be drawn from any one or more of the twelve hoppers in the tanks. These changes were made during 1931.

The effect of the modifications on the efficiency of treatment before and after the changes is shown in Table II.

TABLE II.—*Comparison of Results—Imhoff Tanks Before and After Changes*

Description	Year	Flow M.G.D.	Settleable Solids C.c. per Liter			Suspended Solids P.p.m.			Total Solids P.p.m.			B.O.D. P.p.m.		
			Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.
Before changes	1930	9.5	2.0	0.22	89	160	83	48	640	518	19	112	86	23
After changes	1933	15.0	4.8	0.38	92	290	77	74	751	526	30	175	74	58

These operating data show the improved results with the modified Imhoff tanks.

Operating and Analytical Data.—The operating and analytical data at the East Side plant have been compiled in Table III, which shows the flow treated and the analytical data for two years.

WEST SIDE PLANT—CHEMICAL-MECHANICAL

The West Side plant receives sewage from the westerly portion of Dearborn. This area covers 6820 acres and its population of about 12,000 contributes, including infiltration, about 1.75 m.g.d.

This plant is the chemical-mechanical plant installed by the Filtration Equipment Corporation.

Since descriptions of details of this plant have appeared in literature in the past only the following brief outline is included.

TABLE III.—*East Side Plant. Results of Operation*

Sewage Treated M.G.D.		Settleable Solids			Suspended Solids			B.O.D.		
		C.C./L.		Per Cent Removal	P.p.m.		Per Cent Removal	P.p.m.		Per Cent Removal
		Influent	Effluent		Influent	Effluent		Influent	Effluent	
	1932									
14.30	May	3.5	0.6	83	274	105	62	86	38	56
14.20	June	2.0	0.3	87	146	65	56	85	46	46
15.00	July	2.0	0.6	70	144	74	49	168	132	21
10.18	August	2.0	0.4	80	118	67	43	87	66	24
13.30	September	3.8	0.2	95	223	73	67	99	47	53
15.77	October	4.4	0.2	95	176	59	66	97	53	45
18.55	November	5.0	0.2	97	183	33	82	58	26	55
18.30	December	4.5	0.3	94	150	38	75	95	32	66
	1933									
19.50	January	5.5	0.2	97	152	32	79	74	22	70
18.10	February	3.3	0.5	85	108	47	56	75	36	52
17.80	March	7.3	0.4	94	286	47	84	165	40	76
18.55	April	2.3	0.3	87	111	42	62	61	27	56
16.08	Average	3.8	0.35	91	173	57	67	89	45	49
	1933									
20.05	May	2.6	0.3	88	165	48	71	70	23	67
18.08	June	3.8	0.3	91	231	66	72	118	53	55
17.30	July	3.2	0.2	93	202	63	70	128	63	51
14.40	August	5.1	0.3	95	309	64	79	192	89	53
13.50	September	4.3	0.5	88	300	76	75	204	90	56
12.66	October	5.5	0.6	90	364	78	78	192	81	56
12.43	November	6.2	0.3	96	326	70	88	228	91	60
9.62	December	8.8	0.3	97	515	88	83	390	92	77
	1934									
14.40	January	4.6	0.3	94	248	74	70	145	64	56
12.37	February	4.5	0.4	91	207	93	55	170	98	42
10.30	March	5.4	0.5	92	323	114	65	168	87	47
14.13	April	4.2	0.45	89.5	295	89	70	95	46	52
14.93	Average	4.8	0.37	92	290	77	74	175	73	58

Description.—This plant contains Laughlin travelling, continuous-belt type screens with ¾ in. openings; a pumping station with four pumps with capacities of 2, 3, 7 and 12 c.f.s., together with storm water pumps of 30 and 60 c.f.s. capacities. No removal of grit is practiced. West Side sewage and East Side sludge are pumped to two baffled mixing channels, each 4 ft. wide and 24 ft. long. Chemicals are added in these channels.

TABLE IV.—*West Side Plant*

	Rainfall and River Discharge					Sewage Pumpage Million Gallons per Month			
	Recorded Rainfall* Inches	Normal Rainfall Inches	Per Cent of Normal	River Rouge Discharge† c.f.s.	Sewage and Storm-Water	By-passed	Treated	East Side Sludge Treated	Composite Volume
1932									
May	5.42	3.28	169	494	38.41	10.87	27.54	14.07	41.61
June	1.35	3.56	38	149	27.50	9.17	18.33	14.50	32.83
July	3.11	3.32	94	62	25.12	0.79	24.33	3.21	27.54
August	4.02	2.78	154	62	34.61	—	34.61	13.27	47.88
September	4.05	2.90	140	171	92.30	70.30	22.00	10.74	32.74
October	3.78	2.38	159	120	86.74	—	86.74	9.12	95.86
November	1.72	2.44	71	215	115.71	33.53	82.18	7.59	89.77
December	3.57	2.35	152	451	203.33	141.58	61.75	7.13	68.88
1933									
January	1.18	2.07	57	409	119.19	27.51	91.68	5.41	97.09
February	1.49	2.18	68	196	114.13	39.86	74.27	5.34	79.61
March	2.25	2.40	94	351	140.12	47.50	92.62	4.71	97.33
April	2.61	2.46	106	665	156.13	92.36	63.77	5.12	68.89
Total	34.55	32.05		3345	1153.28	473.46	679.82	100.20	780.02
				Daily Average					
Average	2.88	2.67	108	279	3.16	1.29	1.87	0.27	2.14
May	3.29	3.28	103	955	113.93	81.33	32.60	4.70	37.30
June	1.19	3.56	33	121	82.51	32.65	49.86	5.56	54.52
July	2.47	3.32	74	85	78.72	14.52	64.20	5.48	69.68
August	2.24	2.78	81	52	49.16	1.77	47.39	3.87	51.26
September	1.94	2.90	67	44	44.12	—	44.12	4.00	48.12
October	1.45	2.38	61	52	60.98	—	60.98	2.73	63.71
November	1.68	2.44	69	83	69.67	—	69.67	.915‡	69.67§
December	1.38	2.35	59	131	56.68	—	56.68	.725‡	56.68§
1934									
January	1.65	2.07	80	208	50.87	—	50.87	.540‡	50.87§
February	0.47	2.18	22	183	40.80	—	40.80	.388‡	40.80§
March	2.89	2.40	120	290	48.89	3.78	45.11	.570‡	45.11§
April	3.12	2.46	112	635	95.75	43.76	51.99	.480‡	51.99§
Total	23.77	32.05		2839	792.08	177.81	614.27	29.958	639.71
				Daily Average					
Average	1.98	2.70	73.5	246	2.17	0.49	1.68	0.082	1.76

* Recorded by U. S. Weather Bureau at station about seven miles from West Side Sewage Plant.

† At Greenfield Road discharge is average.

‡ East Side sludge treated separately in South Clarifier.

§ West Side sewage only.

Lime slurry and paper pulp are prepared in pebble mills, each 4 ft. in diameter and 6 ft. long.

Two 60 ft. Dorr traction type clarifiers are equipped with Laughlin magnetite filters. The filters are eight feet wide about the periphery of the tanks and are composed of a bronze screen with 1 m.m. openings, above which is 3 inches of magnetite. Magnetite is graded between screens of 10 and 16 mesh. The rated capacity of the filter at 4 m.g.d. per tank is 3 gal./sq. ft./min.

Sludge dewatering is accomplished on two 8 ft. by 12 ft. Oliver continuous vacuum filters. Filter cake is discharged onto belt conveyor and finally disposed of on a sludge dump.

Operating and Analytical Data.—The following tables show the operating and analytical data of the Dearborn West Side plant for the two years since the plant was started.

Table IV shows the rainfall, discharge of Rouge River, into which the effluent from the West Side plant flows, and quantities of sewage and sludge handled at this plant.

Table V shows the analyses of East Side sludge, West Side sewage, and composite liquor influent and effluent of the Laughlin clarifiers, until November, 1933. From November, 1933, through April, 1934, East Side sludge was pumped intermittently and stored in the south clarifier until filtered on the Oliver vacuum filter.

Table V also shows the chemicals and paper used in pounds per month both for sewage coagulation and sludge conditioning.

In starting this plant it was necessary to proceed cautiously. The experimental plant provided some information of value, but the sewage treated experimentally was absolutely different from that received in the new plant.

Treating sludge and sewage as a strong composite mixture was a new procedure. Various proportions of each had to be tried to determine the best composite mixture. The determination of concentration of sludge pumped from the East Side plant proved to be very important from the standpoint of economical chemical dosage. In an endeavor to determine the most satisfactory method of obtaining efficient and economical results, the operation of the plant and chemicals used were varied to a considerable degree from time to time. Therefore, the more recent data may be considered as more typical of normal operation. Except for brief periods in one clarifier the full capacity of the plant has not been reached.

Table VI shows the rates of flow in m.g.d, detention periods, rates of filtration through the magnetite and settling rates, based on the actual time the plant was operated, averaging 7 to 17 hours per day for the two clarifiers.

TABLE V.—*Operating Results, West Side Plant*

	Biochemical Oxygen Demand P.p.m.					Chemical Analysis				
						pH			Dissolved Oxygen	
	West Side Sewage	East Side Sludge	Composite*	Effluent*	Per Cent Removal*	West Side Sewage	East Side Sludge	Effluent	Effluent	Per Cent Saturation
1932										
May	80	905	208	36	83	7.8	7.5	9.1	5.6	53
June	154	800	228	35	85	7.7	7.4	8.1	3.8	41
July	267	1060	331	58	83	7.7	7.0	8.5	5.0	37
August	132	1670	650	79	88	8.0	7.1	9.6	1.9	43
September	55	1590	544	31	94	7.8	7.1	8.3	2.5	27
October	70	1358	193	21	89	7.6	7.1	7.6	3.8	39
November	21	1490	121	19	84	7.7	7.3	7.8	6.5	63
December	31	2140	203	15	93	7.6	7.0	8.0	7.3	68
1933										
January	33	1580	118	18	85	7.3	6.9	7.5	5.9	53
February	36	1780	156	21	97	7.4	6.9	7.5	6.5	59
March	61	1950	136	16	88	7.2	6.9	7.3	7.7	68
April	23	2358	192	22	88	7.4	6.9	7.6	6.8	61
Average	80	1557	257	31	88	7.6	7.1	8.7	5.5	51
May	54	2160	302	27	91	7.6	6.9	7.8	4.9	47
June	64	2900	344	31	91	7.7	7.2	7.8	4.0	43
July	136	3450	393	28	93	7.7	6.9	7.7	3.7	39
August	108	3450	361	38	90	7.5	6.9	7.7	2.7	28
September	135	3500	433	31	93	7.6	6.9	7.7	2.9	25
October	135	2690	241	26	89	7.6	7.0	7.6	2.8	28
November	111		111	27	76	7.6		7.8	4.8	48
December	136		136	37	73	7.8		7.8	4.8	46
1934										
January	181		181	32	82	7.7		7.7	3.4	32
February	181		181	41	76	7.7		7.7	3.5	
March	110		110	19	83	7.5		7.7	4.9	44
April	40		40	15	63	7.6		7.7	8.3	72
Average	116	3025	346† 126‡	29	88	7.6	7.0	7.8	4.2	38

* Weighted averages.
† Average of 1st six months.
‡ Average of 2nd six months.

TABLE V (*Continued*)

	Suspended Solids P.p.m.					Total Solids P.p.m.				
	West Side Sewage	East Side Sludge	Composite*	Effluent*	Per Cent Removal*	West Side Sewage	East Side Sludge	Composite*	Effluent*	Per Cent Removal*
1932										
May	215	3,660	791	28	97	738	4,750	1428	544	62
June	347	3,748	775	25	97	918	4,460	1398	622	56
July	494	4,450	825	31	96	957	5,160	1469	476	68
August	343	7,160	2455	42	99	822	7,750	2970	630	79
September	286	7,880	2689	42	99	895	8,600	3350	677	80
October	533	6,480	1101	38	97	1195	6,876	1747	713	59
November	70	6,500	572	28	95	750	7,240	1297	701	46
December	190	7,470	750	34	95	775	7,740	1458	630	57
1933										
January	86	5,500	390	27	93	665	6,140	1177	575	51
February	80	4,550	375	33	91	625	5,450	935	585	37
March	68	3,890	288	25	91	565	7,800	799	535	33
April	52	7,125	574	30	95	576	7,762	1170	560	52
Average	230	5,701	965	32	95	790	6,644	1600	604	60
May	192	1,364	1236	35	97	756	8,750	1750	606	65
June	165	12,126	1358	44	97	747	12,770	1968	670	66
July	542	11,300	1320	32	98	1120	11,830	1900	650	66
August	298	9,130	927	38	96	869	9,670	1495	597	60
September	329	9,000	1082	41	96	847	9,125	1479	539	64
October	268	9,370	622	23	96	745	9,258	1042	508	51
November	206	—	2080	19	99	658	45,400	664	531	20
December	206	—	1975	22	99	690	56,370	680	547	20
1934										
January	372	—	374	15	96	840	50,800	863	551	36
February	214	—	225	16	93	724	57,000	634	475	25
March	224	—	2272	20	99	629	43,100	710	585	18
April	158	—	161	23	86	707	42,800	730	636	13
Average	265		1136	27	98	778	29,740	1160	575	50

* Weighted averages.

TABLE V (*Continued*)

	Chemicals								
	Sewage Coagulation Pounds					Sludge Conditioning			
						Prestolite Lime and Ferric Chloride		Prestolite Lime and Calcoag	
	High Calcium Lime as CaO	Prestolite Lime as CaO	Ferric Chloride†	Ferric Sulphate*	Waste Paper	As CaO	Anhydrous Ferric Chloride	As CaO	Calcoag
1932									
May	—	41,451	12,000	—	18,030	45,820	—		
June	—	14,732	8,203	396	10,479	40,260	—		
July	—	20,750	5,010	3,742	6,774	36,140	—		
August	—	106,175	16,382	—	17,436	102,930	—		
September	4,724	19,044	15,630	—	12,682	53,200	—		
October	4,882	19,766	26,089	—	26,801	167,200	—		
November	11,200	304	5,146	—	18,225	81,223	21,960		
December	927	13,088	6,865		18,516	63,860	16,620		
1933									
January	—	17,025	238	14,077	13,711	77,400	16,570		
February	—	24,422	2,700	11,912	18,581	39,540	9,015		
March	—	25,765	—	12,222	15,433	36,960	9,900		
April	4,421	12,572	6,913	6,768	11,945	32,985	6,795		
Total	26,154	315,094	105,176	49,117	188,615	777,518	80,860		
May	3,505	19,817	5,761	5,386	10,419	44,355	8,490	5,444	2,350
June	—	31,312	6,576	7,973	12,898	63,241	16,290	12,048	6,615
July	—	25,214	11,514	10,120	1,880	100,830	22,180	11,400	6,460
August	—	17,244	—	11,249	2,025	83,800	17,640	5,846	2,460
September	—	31,470	—	25,052	—	56,995	12,334		
October	—	20,442	14,797	4,745	904	87,040	15,210		
November	10,650	—	8,442	15,120	10,240	56,400	13,270		
December	3,543	2,532	5,329	15,903	1,199	65,530	15,360		
1934									
January	—	7,184	20,207	—	—	59,114	12,570		
February	—	7,427	17,855	—	5,650	45,280	10,140		
March	—	7,213	16,341	—	6,040	37,515	10,260		
April	—	4,211	9,698	—	—	27,250	6,180		
Total	17,698	174,066	116,520	95,548	51,255	727,350	159,924	34,738	17,885

* Calcoag—about 75 per cent available ferric sulphate.

† As anhydrous $FeCl_3$.

TABLE VI.—*Summary of Clarifier Operation Data*

Date	Treated M.G.	Rate of Flow	Detention Time Hours	Settling Rate Gal./ Sq. Ft./ 24 Hours	Magnetite Filter Rate Gal./ Sq. Ft./ Minute	Number Clar. Used	Average Number Hours Plant Operated
1932							
May	1.34	1.48	2.8	530	0.90	1	20.8
June	1.09	1.16	3.6	410	0.70	1	22.6
July	0.89	1.48	2.8	525	0.90	1	14.4
August	1.54	2.80	2.9	495	0.85	2	13.2
September	1.09	3.62	2.3	640	1.10	2	7.2
October	3.10	4.74	1.7	840	1.44	2	15.7
November	2.74	3.60	1.1	1270	2.18	1	15.2
December	2.00	4.45	0.9	1570	2.70	1	10.8
1933							
January	3.14	4.50	1.8	795	1.37	2	16.7
February	2.85	4.27	1.9	750	1.31	2	16.0
March	3.13	4.70	1.8	830	1.43	2	16.0
April	2.46	4.13	2.0	730	1.23	2	14.3
May	1.33	2.40	3.40	425	0.73	2	13.3
June	1.82	2.78	2.9	570	0.98	2	15.7
July	2.25	3.08	2.6	545	0.94	2	17.4
August	1.61	2.54	3.2	450	0.77	2	15.2
September	1.60	2.80	2.9	495	0.85	2	13.7
October	2.08	3.24	1.9	810	1.35	2	15.4
November	2.32	2.32	1.8	820	1.41	1	24.0
December	1.83	2.58	1.6	910	1.57	1	17.0
1934							
January	1.64	2.80	1.5	1000	1.70	1	14.0
February	1.46	2.38	1.7	840	1.45	1	14.7
March	1.46	2.26	1.8	800	1.37	1	15.5
April	1.73	2.77	1.5	980	1.68	1	15.0

September 1932, heavy rains, sewage weak, by-passing most of month treating East sludge 8 hrs. day. November and December 1932, treated sewage and East sludge in separate clarifiers. Sewage only used for calculations. June 1933, one clarifier out of service for 8 days, calculations adjusted accordingly. October 1933, one clarifier out of service for 18 days, calculations adjusted accordingly. November 1 to December 15, 1933, 24 hour schedule. April 1 to 31, 1934, 24 hour operation.

Periods of Operation.—For proper interpretation of results, the two years of operation are preferably divided into four major periods. These periods summarize various changes in amount of flow and character of East Side sludge and West Side sewage delivered to the plant, and finally the treatment of West Side sewage separate from East Side sludge. The divisions and characteristics of the various periods are as follows:

Period 1—May 1 to September 30, 1932.—During this period an average of 830,000 gallons per day of West Side sewage and 365,000 gallons of East Side sludge was handled in one clarifier.

From May 1st until sometime in July the plant was operated 24 hours a day. The remaining part of the period operation was on a 16-hour basis. This schedule consisted of pumping sewage through the plant from 8 o'clock in the morning until midnight. From midnight until 8 A.M. sewage was allowed to accumulate in the West Side interceptor. During this period sedimentation took place in the sewer, so that when pumping was started in the morning the relatively clear and weak supernatant sewage in the interceptor was drawn out first. Later in the day, when the elevation of the sewage in the interceptor was lowered and the velocities increased, the settled solids were picked up and an increasingly strong sewage was then delivered to the clarifiers. In order to equalize the strength of the influent to the clarifier, it was the practice to pump sludge from the East Side plant during the hours that the weak sewage was being pumped from the interceptor.

Period 2—October, 1932 to April, 1933.—During this period the flow of West Side sewage was 2.5 m.g.d. and East Side sludge about 200,000 gallons per day. Operation during most of this period was on a 16-hour schedule, similar to that of the latter part of Period 1, with the flow of a composite mixture equally divided between two clarifiers.

For the months of November and December a flow of 2.9 m.g. in 16 hours of relatively weak West Side sewage was treated in one clarifier practically without addition of any chemicals for coagulation.

Just before the beginning of the second period additional sewers were connected to the interceptor, which accounts for the increased volume of sewage treated. The strength of the sewage was materially decreased, primarily because of excessive infiltration of ground water. The calculated quantity of this infiltration is 900,000 gallons per day. This accounts for the lower suspended solids content and B.O.D. during the same period.

Period 3— May 1 to October 31, 1933.—The third period of operation includes the last six months that West Side sewage and East Side sludge were mixed and treated as a composite. A flow of 1.5 m.g. sewage and 143,000 gallons of sludge was treated in two clarifiers on a 16-hour schedule, same as in Period 1 and 2. Particular attention was given to close control of chemicals added and pH value of the effluent.

Period 4—November 1, 1933 to April 30, 1934.—The fourth period of operation undoubtedly is the most interesting and has a broader application, because during this period West Side sewage and East Side sludge were not mixed but were treated separately in separate clarifiers.

The sewage tributary to the West Side plant was chemically treated,

then settled and filtered in the north clarifier. The East side sludge was pumped directly to the south clarifier without the addition of any chemicals.

Sludge from the East Side plant was pumped over in as concentrated as possible condition once every four or five days and stored in the south clarifier, where thickening and further concentration occurred prior to dewatering on vacuum filters. This clarifier was operated on a fill-and-draw basis. This differed from former practice when as weak as possible a sludge was pumped over, necessary for satisfactory mixing with chemicals and West Side sewage for treatment on a continuous basis.

The flows handled were up to an average of 3.0 m.g.d. of West Side sewage in the north clarifier and about 20,000 gallons per day of East Side sludge in the south clarifier.

Until about the middle of December, 1933, the plant was operated on a 24-hour per day basis and since then only 16 hours per day, according to the West Side sewage pumping schedule of previous periods.

Summary and Comparison of Data by Periods.—The principal operating and analytical data are summarized by periods in Table VII.

An average effluent containing 33 parts per million suspended solids and 48 p.p.m. B.O.D. was obtained treating a composite mixture consisting of 1507 p.p.m. suspended solids and 392 p.p.m. B.O.D. Chemical use during this first tuning-up period was excessive, amounting to 1133 pounds of lime (CaO), 336 pounds of ferric chloride and 358 pounds of paper per m.g. of composite mixture treated. Additional lime was added for sludge conditioning.

The high average for use of lime during this period was due partly to trial of excessive lime dosage during August, as shown in Table V.

During the second period closer control of coagulation was exercised and materially less chemicals were used for sewage coagulation, although more for sludge conditioning. The amounts were 225 pounds of lime, 125 pounds of ferric chloride and Calcoag (calculated to $FeCl_3$), and 206 pounds of paper per m.g. An effluent containing 33 p.p.m. B.O.D. and 19 p.p.m. suspended solids was obtained. The composite mixture received for treatment consisted of: suspended solids, 579 p.p.m., and B.O.D. 159 p.p.m., somewhat weaker than during the previous period.

During the third period the composite sewage averaged 1161 p.p.m. suspended solids and 356 B.O.D. The effluent contained 35 p.p.m. suspended solids, practically the same as the first two periods, while the B.O.D. in the effluent was 30 p.p.m. An attempt was made to operate with an effluent as near a pH value of 7.8 as possible. The chemical consumption was somewhat higher than in the second period but much less than during the first period. The East Side sludge and West Side

TABLE VII.—*Summary of Principal Data by Periods of Operation*

	May 1932 Sept. 1932	Oct. 1932 Apr. 1933	May 1933 Oct. 1933	Nov. 1933 Apr. 1934[1]
Period	1	2	3	4
Sewage Treated, m.g.d.	.830	2.610	1.58	1.74
East Side Sludge, m.g.d.	.364	.209	.143	.020
Suspended Solids				
West Side Sewage p.p.m.	337	155	299	230
East Side Sludge	5,379	5,931	8,715	—
Composite Influent	1,507	579	1,161	—
Effluent	33	31	35	19
Per Cent Reduction	98	95	97	92
B. O. D., 5 Day				
West Side Sewage	138	55	105	128
East Side Sludge	1,205	1,808	3,035	—
Composite Influent	392	159	356	—
Effluent	48	19	30	28
Per Cent Reduction	88	88	92	78
Chemicals—Pounds				
Sewage Coagulation, per M.G.— Composite Flow				
Calcium Oxide	1,133	225	460	147
Ferric Chloride ($FeCl_3$)[2]	336	126	242	306[5]
Paper	358	206	80	73
Sludge Conditioning, per 1000 Gal. Sludge				
Calcium Oxide	103	166	115	82 } *
Ferric Chloride	—	27	27[4]	19 }
Sludge Cake—Lb.[3]	5,431,781	8,907,140	14,680,900	6,963,700
Per Cent Moisture	57.2	61.1	61.6	67.2
Vacuum Filter, Hr.	2,225	1,673	1,531	1,248
Dry Solids/Sq. Ft. Filter/Hr.	3.9	7.1	10.3	7.5

[1] Raw sewage alone but includes filtrate in untreated sewage.

[2] Includes sludge from East and West Side sewage.

[3] All Calcoag used converted and added to ferric chloride.

[4] Includes Calcoag used during 4 months of period.

[5] Calcoag used for sewage conditioning November and December.

* *Editor's Note.* Data on volume of sludge per m.g. sewage not available, since no separate records were kept for north and south clarifier sludges.

sewage compared in strength more nearly to the first period than the second.

In the fourth period the West Side raw sewage treated alone in the north clarifier contained an average of 230 p.p.m. suspended solids and 128 p.p.m. B.O.D., and the effluent contained 19 p.p.m. suspended solids and 28 B.O.D. This represented a reduction of 92 per cent of the suspended solids and 78 per cent of the B.O.D. Chemical consumption required for sewage coagulation was low in lime and paper and somewhat higher in ferric chloride.

Results Obtained Treating Normal Raw Sewage Alone.—After the beginning of the fourth period of operation it was soon discovered that the large quantity of filtrate, resulting from the dewatering of the sludge from both clarifiers, being returned to the incoming West Side sewage, caused an appreciable increase in the B.O.D. of the effluent. It was noticed that on the days when the vacuum filters were not operating, and therefore, no filtrate being added to the incoming sewage, the effluent was decidedly lower in B.O.D. Further, it was discovered that the supernatant liquor from the south clarifier, which was being used as a sludge thickening tank, when added to the incoming raw sewage had a decided effect increasing the strength of the effluent.

About the middle of January, 1934, the sludge filtrate was pumped to the sludge settling tank and the resulting supernatant therefrom was discharged gradually back into the wet wall, whence it was pumped with the sewage from the West Side to the north clarifier. This allowed the obtaining of data on the treatment of normal sewage uncontaminated by excessive amounts of filtrate.

It was further discovered during this period that the effluent channel, between the clarifier discharge and the point of sampling was being contaminated, first, by the barometric leg seals of the vacuum filters, second, by floor drains, and third, by a soil sump pump draining the second lowest manhole in the plant. Immediate changes were made in the barometric leg seal and this, together with the modified handling of filtrate showed improved results in the quality of the effluent.

As the vacuum filter filtrate from all the sludges handled at Dearborn amounts to five to ten times the volume and strength that would be obtained from West Side sewage sludge alone, those days when this excessive filtrate was returned to the untreated West Side sewage cannot be classed as typical for normal sewage operation. Therefore, the B.O.D. data for days when no filtrate was present in the untreated West Side sewage are shown in Table VIII.

The average for 85 days between November 1, 1933 and March 31, 1934, when filtrate was excluded from the untreated sewage shows p.p.m. B.O.D. of the influent 130, effluent 20, per cent reduction 85. Calcula-

TABLE VIII.—*West Side Plant. Biochemical Oxygen Demand*

Days when vacuum filter filtrate and supernatant from sludge settling tank was not mixed with incoming West Side sewage.

Date	Susp. Solids Inf.	5-day B.O.D.			Date	Susp. Solids Inf.	5-day B.O.D.		
		Inf.	Eff.	% Red			Inf.	Eff.	% Red
Nov. 4/33	213	128	23	82	Feb. 19	236	180	23	87
5	130	95	17	82	20	391	250	14	94
7	398	262	22	92	21	236	175	14	92
9	68	44	16	64	22	61	68	25	63
11	131	81	19	77	23	102	128	25	80
12	189	91	23	75	25	136	103	17	84
17	74	63	24	61	28	130	119	19	84
18	167	117	30	74	Mar. 1	254	140	22	84
19	213	133	22	83	2	78	55	16	71
25	312	183	30	84	3	43	50	16	58
26	185	80	16	80	4	60	58	21	64
30	56	65	27	58	5	57	60	19	68
Dec. 2	182	121	34	72	6	662	265	21	92
3	71	36	14	61	7	297	135	22	84
16	57	58	23	60	8	237	140	16	89
17	831	380	36	91	9	180	88	20	77
23	240	160	26	84	10	86	97	25	75
24	292	135	26	81	11	518	310	24	92
25	42	60	14	77	12	158	160	21	87
30	120	145	32	78	13	93	65	20	69
31	29	47	14	70	14	534	160	17	89
Jan. 1/34	484	190	13	93	15	150	150	16	89
6	237	195	36	82	16	151	113	18	84
12	352	175	33	81	17	68	74	33	55
13	34	26	11	58	18	58	90	12	87
14	725	220	11	95	19	70	70	20	71
15	505	215	24	89	20	40	51	17	67
17	77	68	17	75	21	33	51	27	48
18	231	130	33	75	22	1354	300	25	92
20	99	160	27	83	23	286	112	30	73
21	58	60	19	68	24	270	118	16	86
22	354	210	17	92	25	267	130	23	82
23	1298	265	13	95	26	72	75	16	79
26	1050	440	27	94	27	18	45	17	62
27	99	78	7	91	28	114	78	18	77
28	93	60	10	83	29	130	79	20	75
29	104	103	18	83	30	102	32	8	75
Feb. 1	49	68	22	68	31	516	52	5	90
4	138	119	25	79					
5	207	150	22	85	Average	236	130	20	85
6	195	175	22	87					
8	166	130	20	85					
10	197	285	18	94					
11	300	195	12	94					
12	241	136	25	82					
13	486	235	15	94					
14	30	60	13	78					

tions from analyses of filtrate will indicate that filtrate from normal West Side sewage sludge would add not more than 1 or 2 p.p.m. B.O.D. to the West Side effluent.

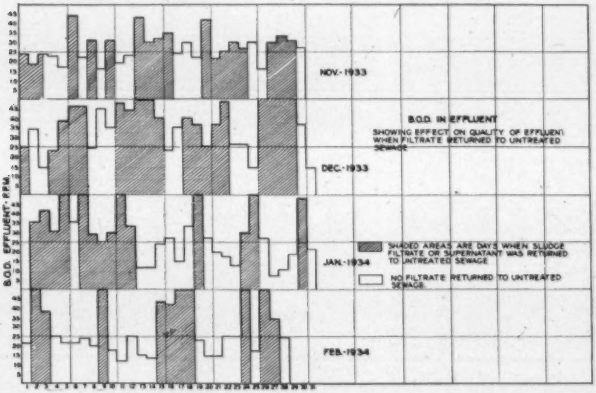

B.O.D. EFFLUENT P.P.M.
NOV.-1933
DEC.-1933
JAN.-1934
FEB.-1934
B.O.D. IN EFFLUENT
SHOWING EFFECT ON QUALITY OF EFFLUENT WHEN FILTRATE RETURNED TO UNTREATED SEWAGE
SHADED AREAS ARE DAYS WHEN SLUDGE FILTRATE OR SUPERNATANT WAS RETURNED TO UNTREATED SEWAGE
NO FILTRATE RETURNED TO UNTREATED SEWAGE

FIG. 1.

Figure 1 shows graphically the B.O.D. of the effluent when either filtrate or south clarifier supernatant was returned to the untreated sewage, as compared with those days when no supernatant or filtrate was returned. The daily results for March, 1934, in Table VIII are of interest since no filtrate was returned to the untreated sewage; the averages show B.O.D. of influent, 110 p.p.m., effluent 19 p.p.m. and removal 82 per cent.

Unusually high suspended solids contents as shown in Table VIII for January 23rd and 24th, March 22nd, and other days are the result of occasional pumping-down and flushing of wet well. This procedure, together with 16-hour operation of plant, explains the unusual variation. At the present time, if conditions will allow, the wet well is pumped down and flushed out daily.

Data plotted for 85 days on raw sewage without filtrate as shown on Fig. 2 indicate that the percentage B.O.D. removal varied according to the strength of the influent, higher percentages of removal being obtained when the influent was stronger. The plot also indicates that, within practical limits, an effluent containing about 20 p.p.m. B.O.D. was obtained at Dearborn irrespective of the strength of the original sewage.

Sludge Dewatering.—All of the East and West Side sludge was sat-

isfactorily handled at the West Side plant on the two 8 ft. by 12 ft. vacuum filters, operating about 8 hours per day. Sludge produced has been disposed of without nuisance by dumping to fill low places on plant grounds. It is the intention, however, to dry and incinerate the filter

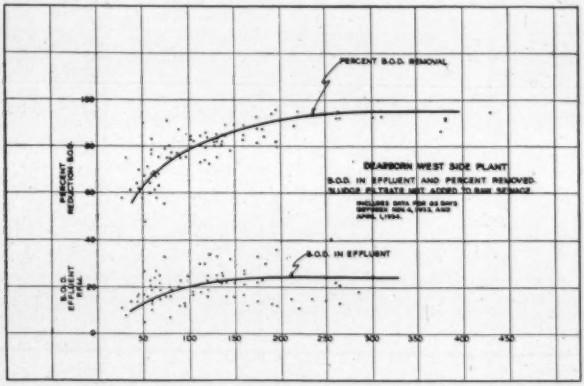


FIG. 2.

cake, and bids for such equipment are to be in hand before this report is published.

Table IX shows the data by months of sludge handled, cake produced, moisture content of wet sludge and sludge cake, and yield on vacuum filters.

Sludge having a solid content of 8.3 to 15.3 per cent solids was drawn from the clarifiers, conditioned with chemicals and dewatered on the vacuum filters.

Probably the most important lesson learned during the first year was in the operation of the vacuum filters. During the first period the filters were operated 2225 hours, producing 3.9 pounds of dry solids per sq. ft. of filter per hour, with an average moisture content in the filter cake of 57.2 per cent. During the second period the filters operated 1673 hours, producing a 61.1 per cent moisture filter cake or 7.1 pounds of dry solids per sq. ft. of filter per hour.

The increase in sludge production from the vacuum filters was the direct result of changing the chemical dosage of sludge conditioning, as well as certain minor mechanical changes on the filters. During the first period lime only was used as a conditioning agent, while during the second period ferric chloride was used in conjunction with lime. This re-

sulted in some increase in cost, but higher filter rates, and a decrease in power and labor costs.

Still further improvement was attained in the operation of the vacuum filters during the third period. The quantity of sludge pro-

TABLE IX.—*Sludge Dewatering Vacuum Filters*
Sludge from North and South Clarifiers

	Wet Sludge Gallons	Wet Sludge % Solids	Filter Cake Pounds	Filter Cake Per Cent Moisture	Dry Solids* Pounds	Filter Hours	Dry Solids* Per Sq. Ft. Filter Per Hour Pounds
1932							
May	534,000	10.4	1,195,700	61.4	462,100	710	2.2
June	429,000	11.6	898,500	59.8	360,600	300	3.9
July	277,500	12.6	661,000	56.7	296,300	329	3.0
August	636,000	13.6	1,740,700	52.9	750,500	470	5.3
September	427,200	11.0	935,881	55.3	418,493	316	4.9
October	673,500	13.7	1,754,130	53.6	814,334	488	6.0
November	657,000	11.9	1,767,998	61.1	684,091	313	8.1
December	516,000	12.0	1,344,652	62.2	497,303	246	7.3
1933							
January	525,000	11.7	1,294,412	61.9	495,062	227	7.4
February	363,000	10.9	917,066	62.9	338,004	151	7.6
March	339,000	10.6	892,450	64.7	315,104	171	6.2
April	340,500	12.4	936,532	61.7	358,376	177	7.1
Total	5,717,700		14,338,921	714.2	5,790,267	3,898	69.0
Average	476,475	11.7	1,194,911	59.5	482,522	325	5.75
May	396,600	14.0	1,179,700	61.5	463,000	168	9.2
June	642,000	15.3	1,934,450	61.1	830,370	267	10.4
July	1,058,700	14.1	4,003,150	60.4	1,242,435	436	9.5
August	777,000	15.0	2,375,950	59.5	964,590	289	10.4
September	482,100	12.7	1,403,650	63.1	518,680	150	11.4
October	726,000	11.7	2,043,100	64.0	731,950	221	10.8
November	708,900	9.2	1,740,900	68.0	553,000	225	8.2
December	739,200	8.9	1,775,700	68.5	562,100	213	8.8
1934							
January	683,100	10.1	1,852,600	68.3	587,480	266	7.4
February	572,850	8.9	1,381,850	64.9	439,970	228	6.4
March	457,400	8.3	1,103,400	70.2	329,100	189	5.8
April	359,700	10.2	850,150	63.6	314,550	127	8.3
Total	7,603,550		21,644,600		7,525,225	2,779	
Average	635,296	11.5	1,803,550	64.4	627,102	231	9.0

* Excluding lime.

duced exceeded the quantity in the first two periods combined. The total time of operation of the filters was only 1531 hours, but the production of dry solids per sq. ft. of filter per hour increased from 7.1 pounds to 10.3 pounds. A material reduction in lime for sludge conditioning is recorded.

A material reduction in the chemicals used for sludge conditioning was accomplished during the last period. No chemicals were added to the South clarifier prior to conditioning for application to the vacuum filters. Although a lower yield and higher moisture content was obtained than during the previous period, the lesser amount of sludge received at the plant was readily handled.

The cake produced had a moisture content of 67.2 per cent and the vacuum filters yielded 7.5 pounds per sq. ft. per hour on dry basis.

During the past year no continuous effort has been made to obtain a low moisture content in the filtered sludge, because the sludge cake, as produced, was hauled to a dump in the immediate vicinity of the plant. The drums of the filters have operated at top speed; the main thought being to accomplish the dewatering of sludge as rapidly as possible to save labor and cost of electrical energy.

TABLE X

	Operating Cost Data East Side Plant		Operating Cost Data West Side Plant	
	May 1/32 Apr. 30/33	May 1/33 Apr. 30/34	May 1/32 Apr. 30/33	May 1/33 Apr. 30/34
Salaries	$12,263.12	$10,397.00	$12,498.44	$13,699.56
Wages	2,398.10	1,343.05	7,814.90	7,761.38
Electricity	13,241.21	9.623.36	7,279.29	4,775.20
Chemicals			6,955.45	7,087.36
Fuel and Gas	171.22	175.99	2,339.99	3,461.18
Supplies	95.60	68.22	450.04	661.72
Equipment Maintenance	202.63	297.18	370.71	397.01
Laboratory Supplies	173.89	—	269.77	186.51
Oil and Grease	62.73	23.11	111.30	93.98
Telephone	98.67	102.21	192.60	184.61
Equipment	26.25	7.45	98.83	386.68
Miscellaneous	207.80	—	460.37	248.99
Total	$28,941.22	$22,037.57	$38,841.69	$38,944.18

Operating Costs and Cost of Plant.—The total annual costs of operation are practically identical for the two years. As Table X indicates, there have been increases in cost of some items and decreases in others.

More men have been employed during the last period of six months than before. This increase was necessary to handle the greater amount of sludge produced and is reflected in cost by the increase of $1200 in salaries. The quantity of sludge cake produced during the second year exceeded the first year by over 7,300,000 pounds.

There was a decided decrease in the cost of electricity for the second year. The $2500 reduction is accounted for by a $925 saving in storm-water pumping; a $730 saving in sewage pumping; and the balance in operation of lights and treatment equipment.

In spite of an increase of over 7,300,000 lbs. of filter cake production only a small increase of about $130 for chemicals will be noted. Although the composite volume of sewage and sludge treated was less the second year by about 140,000,000 gallons the quantity of sludge cake handled was much greater the second year as indicated above.

The remaining major cost item is for fuel and gas. The entire plant being under one roof is completely heated. Oil is used for fuel. A much colder winter with higher unit cost of fuel accounts for the increase of over $1100 in 1933.

Since the West Side plant serves as the point of disposal for East Side plant sludge the problem of quoting operating costs in terms of dollars per million gallons is indeed complicated, if not impossible.

The contract costs of the improvements to the East Side plant, the sludge line and the complete West Side plant were as follows:

East Side Plant		$ 32,783.00
Sludge Line		49,842.43
West Side Plant		
General Contract	$242,000.17	
Pump Contract	46,561.06	
Equipment Contract	167,613.67	
Engineering, Inspection, etc.	22,678.08	
Total		$478,852.98

The general contract included superstructure and pump well; concrete portion of clarifiers; heating, lighting, ventilating, roadways, outside grading and miscellaneous items.

The pump contract covered the furnishing and installation of sewage pumps and motors, necessary electrical installations for same, and venturi meter.

The equipment contract included travelling screens, conveyors, pebble mills, Oliver filters and accessories, Dorr sludge scrapers, Laughlin magnetite filters and cleaners, sludge and lime pumps, ferric chloride generator and all other equipment necessary for the sewage treatment process.

Conclusions

The results obtained and the cost of operation during the first two years have not only been satisfactory but highly pleasing to the officials of the City of Dearborn. The quality of effluent produced has exceeded that expected two years ago. The cost of operating has been within the estimated amount set up when the plant was ordered built.

Much credit is due the supervisors and operators of the plant for this accomplishment. As stated before there was no precedent to follow and every step in the operation had to be made with caution to keep within the budget estimated for operating and the limits of quality required by stream conditions.

All through the past two years the writer has provided for the carrying out of many experiments and much study looking to the improvement of operations at reduced costs. By the time this article is published contracts will have been awarded for making certain alterations and additions, as well as the installation of a sludge incinerating unit. These improvements will be fully described at a later date.

PAINTS FOR SEWAGE WORKS*

By W. T. McClenahan

Senior Civil Engineer, Sanitary District of Chicago

Several years ago the Sanitary District of Chicago, under the direction of Mr. Philip Harrington, Chief Engineer, began tests of some 250 paints and varnishes for use on metal work in and about sewage. These tests were practically completed a year and a half ago.

Exposures selected for the tests were believed to be typical of our sewage works conditions and were as follows:

1. In Raw Sewage: Panels were partly submerged in the flow compartment of an Imhoff tank at the West Side Sewage Treatment Works.
2. In Aerated Sewage: Panels were partly submerged in a final settling tank following aeration in the activated sludge tanks at the North Side Sewage Treatment Works.
3. In Sewage Gas: Panels were placed in a box built over flowing raw sewage in the screen rack room of the North Side Sewage Pumping Station.
4. In Air, Sunlight and Weather with Some Sewage Gas Present: Panels were placed on racks built 45° to the sun in the south between two batteries of Imhoff tanks at the West Side Treatment Works.

The primary purpose of these tests was to determine the useful life of the various paints but along with this determination certain concurrent information of value was secured. The most important concurrent data related to the color reactions of various pigments and vehicles to sunlight and hydrogen sulphide.

In this paper I will briefly outline the testing methods, discuss factors which we concluded were of importance in the destruction of paint films and make a few suggestions for some of the more important paints.

Any conclusions stated should be understood to apply only to our own specific conditions.

I find that frequently I change my views with regard to our paints principally for two reasons:

1. Practical application of a given specification based on our tests often brings out new facts not previously noticed. Sometimes also unsuspected difficulties arise in applying the paint as specified so that modifications must be made.

* Published by Courtesy of the Illinois Association of Sanitary District Trustees. Presented at Eleventh Annual Convention, Waukegan, Ill., June 13, 1934.

2. The paint industry is continually improving old materials and developing new ones so that original tests do not always specifically and accurately cover the new or improved materials.

Testing Methods

In planning the testing program it was thought desirable to make the tests as comparable as possible. For that reason the variable factors which may affect paint life other than paint composition were rendered as nearly uniform as possible for all panels. The panels were made of the same grade of steel, prepared and cleaned in the same way, painted (so far as practicable) by the same man and allowed to dry inside the laboratory under practically the same drying conditions until they were placed side by side in the exposure racks.

Proprietary paints were taken from the manufacturer without analysis although we did ask the maker for an approximate formula so that our general conclusions could be more accurately drawn. A representative of the manufacturer was invited to be present when his panels were being painted and was allowed to see his panels from time to time if he so desired.

Practically all of the paints made to our own specifications were made by a single reliable manufacturer. These paints were used without check analysis.

The panels were of No. 16 B.W. gage "automobile grade" sheet steel cut 8 inches wide by 18 inches long, for the submerged panels, and 8 inches wide by 10 inches long for the other panels. Two ½-inch holes were punched along one 8-inch edge, 4¾ inches apart and ¾ inch down from the top. The holes afforded means for suspending the plates from wooden pegs in wooden holders. A wooden retainer strip screwed down over the pegs and over the face of the panel kept them from falling off the holder.

Except for the air exposure six painted panels were hung from one 2 by 4-inch holder, 3 feet long, both sides of the holder being utilized for suspending plates. This assembly made a very convenient and not too heavy piece for one man to handle in and out of the racks in which they were hung. For the air exposure the panels were fastened directly to the racks by means of similar wooden pegs and retainer strips built into the racks themselves.

The steel panels were cut, punched and pickled by the fabricator before delivery to our laboratory and remained in dry storage in the laboratory until they were wanted. Just before painting they were thoroughly polished with an air-driven rotary wire brush. The finished surface appeared bright but was finely scored by the wire brush, affording good anchorage for the paint. If a panel was to be painted im-

mediately it was thoroughly washed with benzine or benzol to remove all trace of oil and grease. If it was not immediately painted after wire brushing it was lightly covered with machine oil which was later removed with a benzine or benzol wash when painting work was actually ready to go forward.

In a few instances the panels were purposely allowed to rust before painting. A few panels were also prepared of galvanized steel.

To identify the panels a number was given each paint or paint combination. This number was stenciled on the face of the panel underneath the retainer strip to protect the number from weather and damage. This scheme worked quite satisfactorily except for some of the softer asphalts, greases and coal tars which had a tendency to stick to the retainer strip and come off the panel when it was removed.

A letter used with the identification number signified the exposure to which that particular panel was subjected. The same identification number might, therefore, appear on four panels but the letter differentiating between the exposures appeared only once for that particular paint or paint combination.

Inspections were made in general every six months. A special report blank was used. We found that descriptive reports worked out more satisfactorily in our case than ratings on a decimal scale such as was used by the A.S.T.M. in its work. In my opinion there were two objections to a rating system:

1. A man's judgment varies from day to day and even from panel to panel due to an imperfect mental standard of comparison. Where panels show inferior results a panel but very little better than preceding ones appears so much better by contrast that it is overrated and vice versa.

2. Various observers seem to rate paints from different standpoints. I have had the same paint rated by different men all the way from 3 to 8 on a scale of 10. More experienced men would perhaps rate more closely but the fact remains that men's standards vary, no matter how much experience they have had.

Descriptive ratings appear to me to be of more value. We are not so much interested in the relative standing of the various paints submitted as we are in the properties of the various ingredients used in the paints when subjected to the given conditions. Descriptions are of value as a basis for general conclusions concerning the effect on durability and appearance of the various ingredients.

When we started this work three men constituted a party for inspection. This plan worked out quite satisfactorily where the inspectors were new at the work. They helped each other see the things they ought

to see. As funds ran low the party was cut to two men and finally reduced to one man.

Paint Destroyers

As a result of our tests certain factors were shown to be destroyers of paints. These factors may be classified and described under the following heads.

1. Water.
2. Oils and Greases.
3. Hydrogen Sulphide.
4. Sunlight and Air.
5. Miscellaneous Factors Such as Ammonia, Micro-Organisms, Dissolved Oxygen and Physical Damage.

1. *Water.*—Water destroys paints in either or both of two ways:

First: It enters openings in the paint film, *e.g.*, pinholes, skips, deep brush marks, cracks and broken blisters. In entering, it carries with it oxygen and other corrosive substances in solution conveying the corroding substances directly to the steel. Rusting spreads out underneath the paint film and loosens it from the steel. In time the paint scales off, sometimes in large flakes or sheets and sometimes by general disintegration. Because of the underspreading action, therefore, pimples of rust and rust streaks should always be cleaned out thoroughly before repainting, for new paint cannot bridge over loose spots in the old paint coat and be expected to remain intact for any great length of time. Sooner or later the new film also breaks at the neglected spot and rusting begins all over again at the same place.

Second: Water also destroys many paints by combining with the vehicle so that it no longer waterproofs the surface. This hydrolyzing effect in submerged locations is in general indicated by the formation of water blisters. In exaggerated cases, especially with certain types of linseed oil paints, these water blisters become very large. In fact I have seen many panels hanging loosely in a membraneous bag of water. Until the blister or bag breaks, however, rusting of the steel does not seem to take place, indicating either that the fluid in the bag contains some inhibitive salt in solution (such as lead or zinc chromate where these salts were used in the paint) or else that the membrane exercises some kind of selective control whereby corrosive substances cannot pass through to the steel. We made no investigation of this question other than to observe it.

2. *Oils and Greases.*—Out tests indicated that the most destructive agent to paints submerged in sewage was a tar-like accumulation of oil and grease coming from the flowing sewage. The steel seemed to at-

tract these oily substances until a considerable thickness of tarry material was built up over the surface. When an attempt was made to scrape off the accumulation the paint often came off with it. Almost all paints were affected by the coating. Some synthetic resin varnishes seemed to be more resistant than other paints but even they were not entirely immune to the softening influence.

The oily material collected mainly at and near the water line. Wave action and floating debris rubbing against the softened paint tended to remove it, so that invariably the paint at the water line was found to be in far the worst condition. However, this condition may not have been entirely due to the softening action of the oils and greases, but may have been materially assisted in its destruction by the extremely active oxidation which prevails at the water line.

An analysis of a single sample of oven-dried scum, collected from around panels suspended in the final settling tanks following aeration, showed that the scum contained 26 per cent grease and oil, the remainder being largely cellulose. Of the grease and oil about 56 per cent was non-saponifiable so presumably of mineral origin. The rest of the grease and oil being of a fatty nature was no doubt of animal and vegetable origin.

In view of our experience it is my opinion that if a vehicle could be found that would withstand the water, the grease and the oil indefinitely it would be likely to withstand all the other destructive elements encountered in underwater work.

3. *Hydrogen Sulphide.*—Hydrogen sulphide is always present to some extent about sewage works and effects many pigments and some vehicles. Many varnishes are darkened by the gas. Some paint chemists when shown the peculiar type of pin-head blistering characteristic of many phenol-formaldehyde resin varnishes submerged in sewage for a year or more suggested that the phenomenon was due to the hydrogen sulphide reacting with the synthetic resin of the varnish. Other chemists seriously doubted this theory. The scope of our investigation was so limited that it did not permit further studies along this line, but a laboratory test could be devised to determine whether or not the hydrogen sulphide did react in this way.

Generally speaking, however, I think we are less interested in the effect of hydrogen sulphide on the vehicle than we are in its effect on the pigments. Lead pigments all tend to turn a dirty brown. Sometimes, indeed, where the gas was very strong the paints took on a metallic sheen. White lead, especially the carbonate variety, is very much inclined to act that way when exposed to the hydrogen sulphide. Yellow, orange and green colors based on lead chromate darken and both red and yellow oxides of iron are more or less similarly affected. On the

other hand zinc yellow (zinc chromate) turns white so that paints based upon that pigment appear to fade.

As a matter of fact we are considerably limited in our choice of pigments for use about sewage works. Perhaps it will be of interest for me to list the more important pigments available in the market for use with so-called drying oils, which are not seriously affected by hydrogen sulphide.

Whites

Zinc Oxide
Lithopone
Pure Titanium Oxide (and its two combinations with barium and calcium sulphates)

Greens

Chrome Oxide

Yellows and Oranges

Pure Cadmium Sulphide and Cadmium-Selenium Sulphides (and their combinations with barium sulphate to form the so-called yellow and orange lithopones)

Blues

Cobalt Blue
Prussian Blue (not suited however to sunlight exposures or to painting plaster or concrete)

Reds

Pure Toluidine Red (and its combination with barium sulphate)
Pure Selenium Red and Cadmium-Selenium Reds (and their combinations with barium sulphate)

Black pigments of course give no trouble from discoloration and I believe none of the inert pigments used for fillers are affected unless it be calcium carbonate.

4. *Sunlight and Air.*—In outdoor exposures above the water, sunlight and air appear to be very destructive to all paints. The presence of sewage gas and moisture in addition to the sunlight and air makes the exposure extremely severe. Sunlight destroys the vehicle and alters the color of many pigments. The effects on the vehicle may be described as follows:

Chalking: Actinic light destroys the vehicle as a good binder so that the pigment is no longer held firmly in the film but is easily rubbed off. Opaque pigments help to protect the vehicle from light.

Checking and Cracking: Sunlight and air produce chemical changes in the vehicle so that the film looses its elasticity and becomes brittle and cracks from shrinkage and due to the expansion and contraction of the steel underneath it.

Alligatoring: This is a type of checking and cracking peculiar to coal tars and asphalts. In this case a hard crust forms over a softer layer of bitumen. As the crust shrinks irregular black lines open up in the surface exposing the softer material and forming large triangles

all over the surface. As the crust continues to shrink it pulls the softer material away with it and so the steel is robbed of its covering at these lines. Eventually rusting develops at the lines, first at the intersections and then throughout the pattern.

Flowing: Grease coatings and the softer asphalts and coal tars have a tendency to flow off vertical or sloping surfaces, especially in hot sunlight. The top areas of steel construction are therefore often robbed of their coating and so begin to rust.

These are the most noticeable effects of sunlight and air upon the vehicle. In addition sunlight and air affect the color of many paints in either or both of two ways:

(*a*) Sunlight and air may change the chemical composition of the pigment and thus alter the color. Most color changes of this kind move toward the white or gray shades. Prussian blue, red and blue lead and some grades of lithopone are good examples of pigments subject to this type of color change.

(*b*) Sunlight and air by causing chalking often effect certain color changes. The paints appear to fade although the pigments may be totally unchanged. The change in color is entirely due to the change in light refraction and reflection from the surface.

Much experimental work has been done on paints in sunlight and air exposures, notably by the Forest Products Laboratories, the A. S. T. M., the North Dakota Agricultural College and others. The conditions of exposure in all these tests were not identical with our conditions for they had no hydrogen sulphide to contend with, but it seems to be fairly well established by all these tests and checked by our own, that linseed oil is about the most durable vehicle so far developed to withstand sunlight. Another fact brought out by these other tests was that a volumetric ratio of 30 per cent pigment to 70 per cent non-volatile vehicle imparts longer life to outside paints. Either more or less drying oil used in the paint is not so good. Some pigments, however, like lamp black cannot be used in such concentration because of excessively high oil absorption.

5. *Miscellaneous.*—In addition to the major factors causing paint destruction, as above discussed, other factors may at times contribute to paint destruction. These usually minor factors are (*a*) Ammonia, (*b*) Micro-organisms, (*c*) Dissolved Oxygen, (*d*) Physical Damage.

Let us consider these factors for a moment:

(*a*) Ammonia: Occasionally weak solutions of loosely combined ammonia occur in sewage works where the sewage is stale. In the atmosphere above such sewage some free ammonia may exist. If present it is very destructive of paints particularly those of the drying oil type but bituminous paints are also affected.

(*b*) Micro-organisms: It is very likely that micro-organisms of various kinds contribute to the decay of paints in and about sewage. Moulds are known to destroy oil and glue types of paints when conditions are right. A peculiar crumbling of certain types of oil paints which we noticed on some submerged panels was possibly due to biological decay. It was noticed too that in many cases paints below the water line discolored in ways that suggested green mould.

Other factors appeared to so overshadow any possible biological decay effect that it was not seriously considered nor studied in our work but the possibility of such decay must always be kept in mind in designing oil and glue types of paints and in observing their behavior afterwards when they are used in damp locations.

(*c*) Dissolved Oxygen: The presence of dissolved oxygen in sewage in the aeration and final settling tanks of activated sludge plants may have an oxidizing effect on some paints. However we failed to note any marked difference between the panels exposed in the final settling tanks and those submerged in the flow compartment of the Imhoff tanks. If anything the latter case was more severe, the sewage being very stale.

(*d*) Physical Damage: Paint films about sewage works appear to be particularly liable to accidental and mischievous damage. Hard coatings which do not easily shatter withstand this kind of destruction better than softer types. Grease coatings and soft asphalts are particularly subject to physical damage.

Paint Specifications for Specific Purposes

The following deductions and suggestions for specifications for specific purposes have so far resulted from our tests. I cannot, more than briefly outline a few of the more important specifications in this paper.

1. *Priming Paint.*—The most important coat for preserving steel is the priming coat. This is usually the shop coat and so generally receives less attention in construction than the field coats.

Theoretically it should be the hardest coat, due to the softening action of other coats applied over it. It must also furnish the adhesion to the steel and afford good grip for top coats. The pigment must bear the right relationship to the non-volatile oil. Too much oil makes a soft coat which is almost as bad as too much pigment, which lacks binder. Frequently shop coats are little more than colored oils, still further cheapened by addition of far too much thinner. Especially do we find this true in the case of some sprayed coats. From a durability standpoint this is the wrong way to start. The priming coat should be looked upon as the key coat of the entire protective covering and should be properly proportioned.

For practical reasons, the Sanitary District has tried to develop a universal type of priming paint which can be used on any steel with reasonable chance for success. It must be a good water-proofing paint and one that does not discolor with hydrogen sulphide. As previously stated lead pigments cannot be used in decorative paints. There was indication in our tests that red and blue lead, used in undercoats, leached through to discolor top coats, even though they were lead-free. So although red lead proved to be slightly the best pigment for priming steel, black oxide of iron was a close second and was chosen as the base pigment for our priming paint with some zinc chromate added as an inhibitor. This black paint is a little difficult to hide by some decorative paints and so we have been considering the advisability of adding zinc in sufficient amount to throw the color to the gray.

Linseed oil being easily hydrolyzed by water was considered entirely unsuited to an underwater paint. We use a tung-oil varnish instead for the vehicle, adding a small amount of heavy kettle-bodied linseed oil, however, to increase the adhesion to the steel. The resin in the varnish, although not definitely specified, is almost sure to be of the synthetic type to meet the physical requirements. A considerable amount of phenol-formaldehyde resin appears necessary but we limit it to 50 per cent of the total resin due to adhesion difficulties when larger amounts are used. Later developments may cause us to modify these requirements.

Physical tests required of the varnish before it enters the paint are as follows:

1. A hot water test.
2. A cold water test.
3. A hydrogen sulphide test.
4. An ammonia test.
5. A gasoline test.

(We will probably change this to a machine oil test to simulate more nearly actual sewage conditions.)

6. A fatty acid test.

This paint is now being used on new construction. While we have very little actual experience with it we judge from tests of similar paints that it comes nearer meeting our general requirements than anything else we have tried. The greatest difficulty seems to be to get a vehicle which will meet all the physical tests. That difficulty appears to be in the way of being overcome.

One of the disadvantages often noticed with varnish types of paints is that top coats do not adhere well to a fully hardened undercoat. To

overcome this difficulty the gloss must be flattened so that "tooth" will be afforded. To accomplish this result and to decrease the tendency to craze and crack, which is a common fault of most varnishes, our paint has been rather highly pigmented. A pigment to non-volatile volumetric ration of 1 to 2 has been adopted for our priming paint.

2. *Hot Bituminous Coatings.*—Our tests indicated that hot bituminous coatings if properly constituted and applied are the most resistant to sewage conditions of any of the coatings tried. They are, however, rather difficult to apply, especially in confined places where fumes from the hot bitumen stifle the workmen. Moreover, they are rather expensive coatings, costing perhaps 12 to 15 cents per square foot when applied over considerable areas. The coating must be completely intact to be effective. It must be free of pinholes, cracks and missed places for its only virtue is its impervious character. It does not inhibit corrosion in any way and may even accelerate it if the steel is exposed. The coating must not flow in hot weather nor crack in cold weather, for conditions often require that tanks where it is used stand empty for some time while they are being repainted or repaired. To be successful, therefore, the hot coat material should pass the following physical tests.

1. A chipping test.
2. A sagging at 140° F. test.
3. A cracking at 0° F. test.
4. A brittleness or shatter test.
5. A machine oil test.

Hot coatings should average at least $\frac{1}{16}$ inches thick. We specify that "in no case shall the thickness be less than $\frac{1}{32}$ inch and the area less than $\frac{3}{64}$ inch shall not exceed 5 per cent of the total surface."

Good workmanship is essential for success in the use of hot coatings. Only experienced men should be allowed to apply them and inspection should be careful and thorough.

3. *Asphalt Emulsions.*—A second type of coating, the asphalt emulsion, while not nearly so protective as hot coatings, is still very interesting because of the ease of application. Emulsions should be of greater thickness than hot coatings to make them properly effective, and in general they should be applied over a good prime coat of other material such as previously outlined. Roughly, in under-water work they should be about twice as thick as the hot coatings. Apparently the life of the coating is pretty much a function of the thickness.

Our experiments indicated that asbestos fiber in the emulsion improved it, in that it kept the coating from flowing in the heat and made it more resistant to abrasion. In general, the emulsion should not flow at a temperature of less than 125° F. nor become brittle and crack at

low temperatures. It should adhere firmly to the steel and not stick to everything else that comes in contact with the applied coating. We have had considerable trouble of that kind. I am convinced that a re-emulsification test of the dried film should be included in the specifications. We specify that "a coating applied $\frac{1}{16}$ inch thick to a polished steel or glass plate which is allowed to dry at room temperature for 48 hours and then soaked in sewage for 7 days shall remain firmly attached to the plate and not rub off nor markedly discolor the fingers when vigorously massaged with moderate pressure."

Asphalt emulsions are particularly well suited to application on damp steel. In fact, they are about the only thing in common use that can be used where the steel cannot be properly dried for other paint application, as sometimes occurs in tunnels, basements and bridge pits. To be suitable for such locations the emulsifying agent should be such type as will readily evaporate (like ammonia) and cause the asphalt to solidify in spite of the moisture present on the steel.

4. *Outside Paints in General.*—Outside paints should generally be based on linseed oil as the main part of the vehicle. The only exception to this rule is an aluminum paint, which is said to be more durable when based on a tung-oil varnish for the vehicle.

A considerable amount of heavy kettle-bodied linseed oil used with the raw oil will improve the waterproofing qualities and the life of pigmented paints.

Pigments for paints about sewage works should always be selected with reference to their reaction towards hydrogen sulphide, as previously discussed.

We have found aluminum paints very satisfactory for painting elevated water tanks, bridges and steel about concrete structures, which for architectural reasons we desire to be not too prominent. Zinc-dust paints might serve just as well, but have never been tried except on one test panel.

5. *Inside Paints in General.*—Inside paints used for decorative purposes on steel in the dry should in general have a considerable amount of both heavy kettle-bodied linseed oil and spar varnish in the vehicle. The bodied oil, however, makes the paints set more slowly so that they remain tacky for a week or more. To overcome this difficulty in machine enamels I have specified that the heavy bodied oil be cooked with a resin to produce a linseed oil varnish having a Kauri reduction of not less than 80. This resin hardens the coating at the sacrifice of considerable elasticity but seems desirable where the coating is to be rubbed.

In basements, tunnels, galleries and other rather dark but not wet out of the way places we are now using aluminum paints of the same

specifications used in outside paints. This paint gives a pleasing brightness to these dark places and appears to be very durable.

6. *Gilsonite Paint.*—A first-class Gilsonite paint made with tung oil, with no addition of linseed oil, makes an excellent general purpose black paint, although it is not so well suited to sunlight exposures as elsewhere. If well-made, several coats of the Gilsonite paint stand up unusually well in under-water work.

EXPERIMENTS WITH INLET DEVICES FOR SEDIMENTATION TANKS *

By George E. Hubbell

Hubbell, Hartgering & Roth, Inc., Consulting Engineers, Detroit, Michigan

In 1921 the City of Dearborn, Michigan, constructed a sewage treatment plant consisting of coarse screens, pumping station, grit chambers, Imhoff tanks and sludge beds. The effluent discharges into the Rouge River. The plant was designed for a population of 56,000 with an estimated sewage flow of 5.6 m.g.d. Since then both Dearborn and the City of Detroit have increased greatly in population so that today Dearborn has an equivalent connected population of 52,000 and the City of Detroit's Southfield district, a population of 94,000 with a combined sewage flow to be treated of 18.5 m.g.d.

The City of Detroit was faced with the problem of disposal of the sewage from the Southfield District. The city found it necessary either to construct a plant in the vicinity of the end of the uncompleted Rouge Interceptor, or to complete the interceptor, or to negotiate with Dearborn for treatment of the sewage. The firm of Hubbell, Hartgering & Roth was retained by Dearborn to study and report on the above and other matters. As a result of their report it was determined to treat the Detroit Southfield District sewage at the Dearborn Miller Road (East Side) Plant. It was decided that the treatment of the combined Dearborn and Detroit flow would consist of plain sedimentation, with daily removal of the sludge by pumping to a West Side plant equipped with chemical conditioning and sludge filters for dewatering the sludge.

The Imhoff tank plant consisted of four units each approximately 33 ft. by 100 ft. in plan with a total settling volume of 715,000 gallons. At the designed 5.6 m.g.d. rate the detention period is approximately 3 hours and at the 18.5 m.g.d. rate only 55 minutes decreasing to 43 minutes at a rate of 24 m.g.d. It was recognized that unless all parts of the tanks were used to the fullest degree, unsatisfactory results would be obtained with such short detention periods. For economic reasons it was not feasible to construct additional tanks to obtain the longer detention periods usually provided for in design. Instead, all effort was made to develop the most efficient inlet possible with the idea that such an inlet would compensate for the decreased detention period.

Detention periods referred to are total volume displacements, but it is recognized that under no conditions are such displacements realized,

* Presented before the Tenth Annual Conference of the Michigan Sewage Works Association, East Lansing, March 30, 1934.

as the attainment of a uniform velocity through the entire cross section of the flow chamber is never achieved in practice.

The existing inlet facilities of the tanks consisted of the conventional inlet channel along the end, approximately 142 ft. in length. Each tank was equipped with three individual, side-spill, rectangular, adjustable brass weirs, one for each flow channel. With a channel velocity of 2.5 feet per second a very noticeable side-throw was imparted to the water passing over the weirs. This introduced very objectionable conditions, as the sewage was thus given an initial course diagonally across the tank, giving unequal distribution within each tank. In an attempt to overcome this disadvantage, one tank was equipped with V-notch weirs; from observation it appeared that flow conditions in the tank were improved. One of the main objections to either of these types of weirs was the difficulty of obtaining equal division of the sewage between the several flow channels of the tanks. Theoretically, equal division can be obtained by adjusting the individual weirs to compensate for the loss in head in the distribution channel, but under actual conditions this entails more or less labor and once the settings are made, a material change in flow will upset conditions. Because of the labor involved the weirs are usually set by eye. With flows such that an adhering nappe is obtained, it is extremely difficult to estimate the relative quantity of sewage passing over each weir, so that, normally, distribution to the respective channels is variable.

In order to remedy this condition and make possible the proper handling of the increased flow, extensive investigations of the most suitable type of inlet were conducted. It was desired to accomplish two things:

First: To divide the sewage flow into twelve equal parts so that at all times, under all conditions of flow, with a minimum of manual control, each channel would receive its true proportional part of the flow.

Second: Having divided the flow, to distribute it in the tanks in the most suitable manner to promote the settling of suspended solids.

The first problem was solved by the use of orifice-plate control. As the sludge was to be removed daily, the reversal-of-flow feature of the tanks was abandoned, and an inlet conduit was constructed across one end of the tanks located below the water level. Thus, the entire cross section of the conduit is used at all times and as it is of varying cross-section the velocity is uniform throughout its full length. At a rate of 12 m.g.d., the velocity is .465 ft. per second, increasing to 2.32 ft. per second at the maximum rate of 60 m.g.d. Before entering the conduit the sewage passes through a grit chamber, where at the 12 m.g.d. rate the velocity is .7 ft. per second. No material sludging of the inlet conduit takes place. The low velocities give very small losses across the

conduit so that the head on the last orifice does not vary at the 60 m.g.d. rate by more than 5 per cent from the head on the first orifice. At the 12 m.g.d. rate the difference in head is not measurable by ordinary means. Each flowing-through channel is equipped with a 16-inch wrought iron spigot inlet pipe, having an orifice plate of diameter 12.273 inches, set flush with the wall of the inlet conduit. On the other end of the pipe a sluice gate discharges into a wooden distribution structure. Each orifice plate was designed to handle flows varying from 1 to 5 m.g.d., with an actual loss of head varying from .06 ft. to 1.52 ft.

Because of the nature of the installation and in order to aid in manual control, as well as in conducting tests, each orifice plate was equipped with a meter body and electrically connected to a twelve-point master switch and indicating dial. Thus the operator has visual indication of the division of the flow and is also able to detect any change in the condition of an inlet due to stoppage or accumulation of sludge. The following observations are typical of the results obtained without the aid of manual control:

At a total flow of 16.76 m.g.d., the average discharge per orifice was 1.39 m.g.d., with a maximum variation from this average of 2.6 per cent.

At 34 m.g.d., the average discharge per orifice was 2.83 m.g.d., and maximum variation 5 per cent.

At 42 m.g.d., the average discharge per orifice was 3.5 m.g.d., with maximum variation of 1.0 per cent.

The 5 per cent variation represents extreme conditions, a more normal variation being from 2 to 3 per cent. The head lost in the meter equipment at the 24 m.g.d. rate amounts to 0.3 ft., which is a little over 1 per cent of the total pumping head.

Extensive tests were made with a model to determine how best to distribute the water in the tanks. One tank unit was reproduced in wood, using a scale ratio of 1 to 27 as this ratio gave a convenient sized tank to work with and allowed the use of five-eighths inch pipe for the 16-inch inlets. The following types of inlets were tested in obtaining the adopted form:

1. Many sedimentation tanks have been built having inlets consisting of pipes discharging horizontally into the tanks against vertical baffles. Inlets of this type give very poor distribution. When the inlet baffle projects above the water surface, the tendency is for deep flow; when the baffle is narrow and below the surface the trend is for high surface velocity and deep flow, with portions of the tank not used. With no baffle the water is shot through the tank in a stream of high velocity, giving very short detention periods. In the light of the tests and general observation, inlets of this type are not recommended.

2. In order to remedy the undesirable conditions described above,

it was considered that the addition of an upturned elbow would largely overcome the horizontal velocity effect. It was presumed that by discharging upward the energy of the entering sewage would be dispelled by gravity, and that so long as the fountain effect was kept within reasonable limits, the sewage would be placed in the tanks with the least possible disturbance. The results were disappointing. This type of inlet when placed near the surface gives very deep flow of a non-uniform character, no matter how small the rise over the lip of the weir. When placed deep, the tendency is to set up a vertical circulating current or roll in the end of the tank. This type of inlet apparently held no promise of giving the distribution desired.

3. The standard type of inlet has always been the side-spill weir. The tests indicate that fair results can be obtained from ordinary weirs if the sewage is properly brought to the weir. If side-throw is eliminated, head on the weir and drop into the tank kept small, relative good distribution can be obtained, although there is a tendency for deep flow. Contrary to usual practice, the removal of the inlet baffle is of material benefit in the initial distribution of the flow.

4. Under all of the above conditions, tests actually showed better flow conditions with the outlet baffle removed. However, on account of scum conditions it is not feasible to dispense with the outlet baffle, but it should be set at a minimum depth, preferably not over 3 inches.

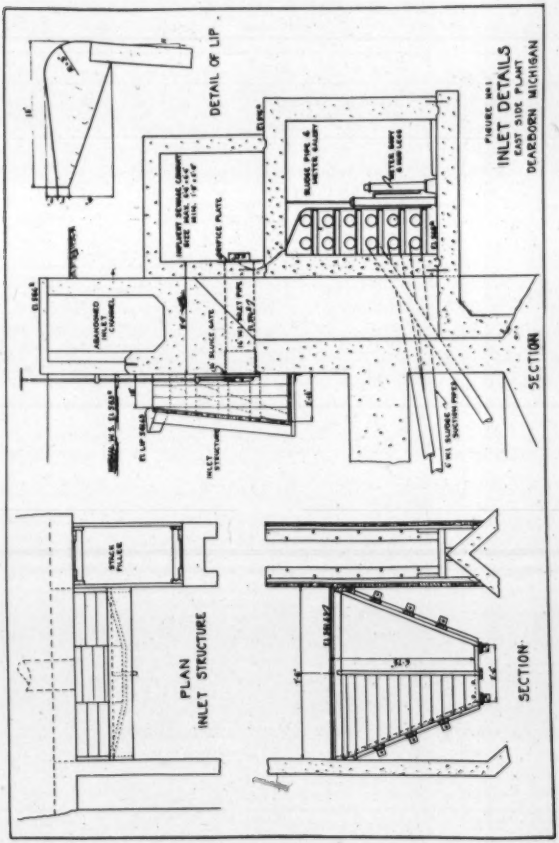
5. Figure 1 shows the type of inlet finally adopted. The actual form of the inlet was determined solely by experiment. Under present average conditions the 16-inch inlet pipe imparts a velocity of approximately 2 ft. per second to the sewage. The shape of the adopted inlet permits this velocity or energy to dispel itself in a whirlpool and vertical rise of decreasing velocity. When the sewage reaches the lip of the weirs it has lost its energy and flows horizontally, over the broad weir lip, into the tank, uniformly distributed.

It was found that the following factors had considerable influence on the flow distribution:

(*a*) The slope of the front of the inlet box, as it influenced the throat area, gave variations in the distribution over the lip of the weir. Slopes of 3 to 11 gave more flow over the sides of the weir, while a slope of 1 to 11 seemed to give uniform distribution.

(*b*) The depth of the weir lip below the surface was found to be 19 inches for best conditions. Less depth gave increased velocities in the final third of the tank and shorter periods of time for the first color of dyes to traverse the tank. Greater depth had substantially the same effect.

(*c*) A protruding goose-necked weir was found most satisfactory for importing to the sewage the proper initial direction of flow. Sharp-crested weirs had a tendency to produce a lip roll.


DETAIL OF LIP
SECTION
PLAN
INLET STRUCTURE
SECTION
FIGURE NO. 1
INLET DETAILS
EAST SIDE PLANT
DEARBORN MICHIGAN

The actual operating results obtained at the plant are the best measure of what was accomplished in the way of improved flow conditions.

Prior to June, 1930, analyses did not include suspended solids determinations at the Miller Road Plant. Suspended solid tests before the alterations were made therefore consist only of the records for the last seven months of 1930. For this period the raw sewage carried an average of 160 p.p.m., the effluent 83 p.p.m. suspended solids. The average flow was 5 m.g.d., giving a detention period of more than three hours. The removal obtained was 48 per cent. This low removal was felt to be partially due to the manner in which the inlet and outlet weirs were then being operated.

Table I shows the total sewage treated and the daily removal of suspended solids, as determined by composites of hourly samples taken over a five-month period after the new inlets were installed. The average amount of sewage treated during the period was 17.1 m.g.d. The detention period was 1 hour. The average removal of suspended solids for the period was 74 per cent of the average of 182 p.p.m. in the influent, leaving 47 p.pm. in the effluent.

The flow has been increased three and one half times and at the same time the removal of suspended solids increased from 48 to 74 per cent. Thus it can be readily seen that metering and proper distribution are amply justified. The costs chargeable to the flow alterations amounted to $16,400 as compared to the original cost of $126,500 for the Imhoff tanks.

Examination of Table I shows that on certain days the raw sewage carries a very heavy load of suspended solids. On such days the per cent removal is extraordinarily high, reaching a maximum of 97 per cent. This heavy load was partially due to the method of operation of the sanitary interceptor in conjunction with the combined sewer system and because of test runs carried on at the West Side Plant.

If all of those days having suspended solid contents of over 300 p.p.m. are removed from the average figure, the results are comparable to the conditions met with at the average sewage treatment plant. Treating the data in Table I in this manner gives an average discharge of 17.1 m.g.d. Detention period was one hour, and removal of suspended solids of 61.5 per cent based on 109 p.p.m. in the influent. It is interesting to note that for the last three months of the period the removal was 65.3 per cent for a detention period of 55 minutes and a suspended solids content in the influent of 89 p.p.m. under the same conditions assumed above.

The maximum recorded daily rate was 23.16 m.g.d., giving a detention period of 44 minutes. The removal on that day was from 121 p.p.m. to 52 p.p.m. or 57 per cent.

TABLE I.—*East Side Sewage Plant, Dearborn, Michigan*
M.G. Sewage Treated and Suspended Solids Removed

	September, 1932			October, 1932			November, 1932			December, 1932			January, 1933		
	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled
1	5.20	86	40	13.01	149	60	18.11	66	47	20.37	81	45	19.58	45	11
2	9.92	43	33	12.19	184	52	18.59	88	52	20.06	45	19	19.10	57	15
3	14.08	140	36	13.34	156	68	18.36	78	34	18.92	127	29	19.62	45	17
4	10.06	217	74	12.87	232	84	18.24	82	41	17.32	33	23	23.16	121	52
5	9.32	79	59	15.14	52	51	17.83	140	37	17.70	32	30	20.93	469	66
6	10.59	208	48	16.39	70	47	18.00	149	28	18.54	165	30	20.20	62	23
7	11.34	92	50	16.60	138	34	18.56	44	29	15.10	124	112	19.36	56	44
8	13.00	68	53	12.80	329	68	22.10	56	22	19.82	33	31	20.20	35	16
9	15.20	56	49	12.97	92	67	21.11	68	35	20.20	19	18	20.42	57	19
10	12.47	486	30	15.54	234	106	19.25	65	11	19.47	74	37	20.44	249	19
11	13.36	521	115	12.35	40	29	19.03	90	33	19.68	48	28	18.35	64	24
12	12.10	141	50	14.09	58	24	8.64	801	72	20.60	126	57	20.13	76	14
13	12.80	163	59	17.88	80	37	14.71	2292	74	19.00	1694	156	18.55	330	20
14	14.52	100	56	18.21	53	40	18.98	125	33	18.10	203	53	17.90	428	34
15	13.82	135	53	18.71	54	40	17.19	133	47	17.85	117	57	17.56	111	19
16	14.89	320	83	15.83	370	61	18.29	149	37	18.15	50	21	17.47	97	38
17	13.05	274	62	17.32	172	86	17.44	294	52	18.12	119	49	17.32	99	66

TABLE I.—*Continued*

September, 1932				October, 1932			November, 1932			December, 1932			January, 1933		
	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled	M.G.	Susp. Solids Raw	Susp. Solids Settled
18	12.38	138	66	16.18	151	82	17.19	1022	42	17.69	90	17	17.30	160	36
19	13.00	104	64	15.41	132	67	17.10	26	13	16.58	161	25	17.50	160	45
20	17.04	81	72	14.80	250	67	20.25	17	8	17.57	125	40	22.30	70	26
21	17.34	96	60	13.74	228	56	19.79	50	43	18.10	130	26	22.75	47	18
22	15.39	123	54	13.92	174	59	20.45	105	26	11.63	178	70	19.37	70	32
23	14.00	96	74	13.75	132	35	20.15	126	42	14.90	154	51	19.34	44	23
24	15.12	1077	444	16.21	280	132	19.04	20	16	15.45	112	20	20.60	100	27
25	12.27	110	52	15.03	154	87	19.97	34	20	17.13	25	18	20.83	707	118
26	14.34	131	82	17.53	104	74	19.56	75	27	17.80	73	8	17.43	260	45
27	16.57	284	55	17.76	150	26	19.55	54	12	18.30	55	30	18.10	93	
28	15.10	66	27	19.75	130	45	19.70	34	18	18.68	41	28	18.90	87	19
29	15.90	68	56	16.53	969	63	20.44	44	35	20.35	53	31	19.46	54	9
30	14.05	1015	63	17.12	64	38	19.56	44	32	18.35	157	44	20.60	28	14
31				17.92	110	74				20.04	205	11	20.30	400	53
Ave.	13.20	238	71	15.77	177	60	18.55	216	34	18.30	150	39	19.50	151	32
Max.	17.34	1077	444	19.77	969	132	22.10	2292	74	20.60	1694	156	23.16	707	118
Min.	5.20	43	27	12.19	40	24	8.64	17	8	11.63	19	8	17.30	28	9
		Red. = 70%			Red. = 66%			Red. = 84%			Red. = 74%			Red. = 79%	

The average removal of settleable solids for the period shown in Table I, as determined by the Imhoff cone, has been 95 per cent.

A check on the removal accomplished by the tanks is given by the following data. For the six months, August through January, 3,134,995 pounds of suspended solids were deposited, according to the recorded removal data, in the Imhoff tanks. During the same period the records show that 3,073,770 pounds of suspended solids were pumped from the tanks by the sludge pumps for treatment at the West Plant. The difference in quantities is less than 2 per cent, a slight difference which speaks very well for the care used both in the laboratory and in the sampling.

Table II shows the monthly average suspended solid removal data

TABLE II.—*Removal of Suspended Solids at the East Side Plant For the Year 1933*

Month	Average Flow, M.G.D.	Suspended Solids, Raw	Suspended Solids, Eff.	Per Cent of Removal	Minutes Detention
January	19.5	151	32	78.8	52
February	18.1	103	47	54.4	57
March	17.8	260	46	82.3	58
April	18.54	114	46	59.6	55
May	20.0	165	48	70.9	51
June	18.1	217	63	71.0	57
July	17.3	202	64	68.3	59
August	14.4	300	65	78.4	71
September	13.5	308	76	75.3	76
October	12.66	367	79	78.5	81
November	12.43	324	70	78.4	82
December	9.62	374	84	77.6	106
Average	16	240	60	75	64

for the year 1933. The average flow was 16 m.g.d., giving a detention period of 64 minutes. The removal accomplished was 75 per cent of the average of 240 p.p.m. suspended solids in the raw sewage. These results are comparable with results at other plants because the sewer system was operated in such a manner that only on a very few days during the year were the suspended solids abnormally high.

For comparative purpose, Table III has been prepared, giving the total suspended solids in the raw sewage, the detention period in hours, and the removal of suspended solids accomplished at several sewage treatment plants. It is quite evident that in the light of the operating results at these plants the results obtained at the Dearborn plant are

very gratifying. The increased operating efficiency together with the small capital outlay required, combine to make additions such as these

TABLE III.—*Removal of Suspended Solids at Several Sewage Treatment Plants**

Plant	Year	Suspended Solids, Raw	Hours Detention Period	Per Cent Removal of Suspended Solids
Marion, Ohio	1925	271	—	65.9
	1926	219	8.9	62.4
	1927	206	9.1	61.6
	1928	191	8	57.7
Flint, Michigan	1928	255	6.6	66.7
	1929	256	6.3	69.3
Syracuse, N. Y.	1927	183	1.3	57
	1928	210	0.75	55.7
Fitchburg, Mass.	1921	389	8.5	85.3
	1927	266	6.5	75.3
	1931	163	6.3	70.1
Worcester, Mass.	1927	288	2.7	55.9
	1928	—	2.5	58.6
	1929	—	2.8	62.8
	1930	—	3.3	59.8
Grand Rapids, Michigan	1930	151	2.33	31
	1931	181	2.05	55.3
	1932	189	2.15	55.6
Pontiac, Michigan.....	1930	248	2.8	67.5
	1931	265	2.7	68

* Data taken from annual reports.

highly worth while and deserving of attention in the design of sedimentation tanks for sewage treatment.

CHLORINE DISINFECTION OF SEWAGE*

By Warren J. Scott and LeRoy W. Van Kleeck

Director and Sanitary Engineer, Bureau of Sanitary Engineering, Connecticut State Department of Health

Introduction

Much has been written concerning the benefits obtained in sewage treatment by the use of chlorine, involving control of odors, improved operation of sedimentation tanks with pre-chlorination, elimination of *psychoda* flies and lessening of pooling on trickling filters, reduction of biochemical oxygen demand, effect on receiving bodies of water, and other considerations. The present discussion is limited mainly to chlorine disinfection of sewage, based on Connecticut experience with destruction of bacteria for the protection of bathing beaches and shellfish areas, with some mention of variations in chlorine demands of different sewages.

Many factors, in addition to the rate of sewage flow, influence the quantity of chlorine needed to satisfy the chlorine absorbing capacity of sewage and to produce an excess of free chlorine required for the destruction of bacteria. Among these may be mentioned the strength, freshness and temperature of the sewage, range in variations of concentration, content of industrial wastes, infiltration of salt water, effects of intermittent discharge of grit chamber washings or digestion tank overflow or sludge bed underdrainage, chlorine contact period, method of application of chlorine, and contact of chlorine and sewage with decomposing sludge and scum. Some of these factors, of course, overlap.

Tests for Efficacy of Chlorine Disinfection

In the field of water purification, the presence or absence of organisms of the *coli-aerogenes* group has been employed for many years as an indication of freedom from intestinal bacteria which may cause human disease. Tonney, Greer and Danforth in laboratory studies of the minimal chlorine death points of various bacteria reached the conclusion that *B. coli* organisms are the most resistant type of bacteria encountered in the intestinal group and are a satisfactory criterion for effective disinfection.

Numerous investigations have indicated the value of the orthotolidin test as a field determination to measure readily the excess or residual

* Presented Before the Spring Meeting of the New England Sewage Works Association, Greenwich, Conn., April 30, 1934.

chlorine, and a correlation between various chlorine residuals, contact periods, and bacteriological examinations, has been worked out to show the chlorine residual content and the contact period desirable for efficient disinfection.

As pointed out later, under "Contact Periods and Chlorine Residuals," and as noted in Tables I, II, III and IV, our experience has shown that occasional unexplainably high bacteria counts and presence of *coli-aerogenes* organisms have occurred in the face of apparently adequate chlorine residuals. The Connecticut State Department of Health has never attempted to set any standard of permissible bacteria content in chlorinated sewage effluents but rather has sought a reasonable content of residual chlorine after a definite period of contact of sewage and chlorine. Both in the regulation of bathing areas and shellfish areas, the tendency seems to be to work toward tentative standards for bacterial quality of receiving bodies of water rather than toward bacterial quality of sewage effluents discharged into the water.

If attempts were made to set bacterial standards for chlorinated sewage, it appears from the data in Tables II, III and IV, that maximum 24-hour bacteria counts at 37½° C., of 100 to 500 per c.c., or the absence of colon organisms in 0.01 or 0.1 c.c. volumes, might be possible criteria.

Neutralization with Sodium Thiosulphate

In measuring the bactericidal action of chlorine upon sewage, it is important that results found through examinations in the laboratory be truly representative of field conditions. It is obviously incorrect to collect a sample of chlorinated sewage or effluent at a plant and allow the sample to be transported or stored, thus providing additional and frequently appreciable contact between the sewage and chlorine, before a laboratory examination is made. The effect of the chlorine may be almost immediately lost in the receiving body of water. The result at the end of the available contact period is of importance in practice. Samples must, therefore, be collected and examined accordingly.

Samples for bacterial examination should be neutralized with sodium thiosulphate at the expiration of the contact period prevailing, unless the laboratory media can be inoculated promptly after sample collection. Our practice in Connecticut has been to add one small crystal of sodium thiosulphate to the sterilized sample bottle when collecting the chlorinated sewage or effluent. Griffin, supervising chemist of the Greenwich, Conn., sewage treatment plants, has tried out the practice of placing sodium thiosulphate crystals in sample bottles before sterilization of the bottles and observations did not indicate any material difference in results obtained as compared with tests of duplicate samples collected by the State Department of Health in bottles to which crystals were added at the time of sampling.

Table I shows a comparison of bacterial results obtained on neutralized samples and samples not neutralized, collected at different plants. It is clearly indicated that the apparent result of chlorination may be quite different in practice than in the laboratory, unless the action of the excess chlorine be stopped by the addition of an anti-chlor to the samples.

TABLE I.—*Comparison of Neutralized and Unneutralized Bacterial Samples*

Sample No.	Contact, Mins.	Chlorine Residual, P.p.m.	Plate Count	*Coli-Aerogenes*, c.c.					
				.0001	.001	.01	.1	1.0	10.0
1	*	1.0 after 10 mins.	18	0	0	0	0	0	0
1A	10	1.0	3,600	0	+	G	G	G	G**
2	*	1.0 after 15 mins.	24	0	0	0	0	0	0
2A	15	1.0	36,000	0	0	+	G	G	G
3	*	0.7 after 10 mins.	75	0	0	0	0	0	+
3A	10	0.7	110	0	0	0	0	+	G
4	*	1.0 after 90 mins.	8	0	0	0	0	0	0
4A	90	1.0	55	0	0	+	G	G	G
5	*	0.6 after 2 mins.	70	0	0	0	+	G	G
5A***	2	0.6	12,400,000	+	G	G	G	G	G
6	*	0.075 after 30 mins.	4,200	0	0	0	0	0	+
6A	30	0.075	36,000	0	0	0	+	G	G
7	*	0.6 after 30 mins.	34	0	0	0	0	0	0
7A	30	0.6	220	0	0	0	0	+	G
8	*	0.2 after 30 mins.	40	0	0	0	0	0	+
8A	30	0.2	700	0	0	0	+	G	G
9	*	0.12 after 30 mins.	43	0	0	0	0	0	+
9A	30	0.12	6,900	0	+	G	G	G	G

* = These samples were collected and brought to the laboratories without neutralization of the residual chlorine. The contact periods were between 15 and 24 hours in most cases. The other samples were collected at the same times but the samples were neutralized with sodium thiosulphate at the end of the contact periods noted.

** = G = Gas forming bacteria which were not confirmed as *coli-aerogenes*. Complete confirmation was carried through only in the greatest dilution showing gas.

*** = It appears probable that the chlorine may not have been thoroughly mixed through the sewage represented by this sample.

Contact Periods and Chlorine Residuals

In the studies at Bridgeport on screened sewage disinfection, Scott and Pool [1] found that satisfactory disinfection was secured in a 10-minute period of contact, although 15 minutes was considered to be safer. Results of bacterial examination of some samples of chlorinated sewage at different plants with varying periods of contact and chlorine residuals are illustrated in Tables II, III and IV.

From the results of our observations on different sewages in Connecticut, it appears: (1) that even with high chlorine residuals, contact periods of 5 minutes or less produce ineffective disinfection; (2) that with 10 to 15 minutes contact, the results are sometimes inconsistent although results of previous investigations in Connecticut and elsewhere indicate that with 15 minutes contact and with chlorine residuals of 0.5 p.p.m. or upward, effective removal of bacteria may be obtained; (3) that with 30 minutes contact, consistently good results can ordinarily be obtained with a chlorine residual of 0.2 p.p.m. or upward, although 0.5 p.p.m. insures more dependable results.

Effect of Temperature

Figure 1 illustrates variations in the chlorine demand of Norwalk sew-

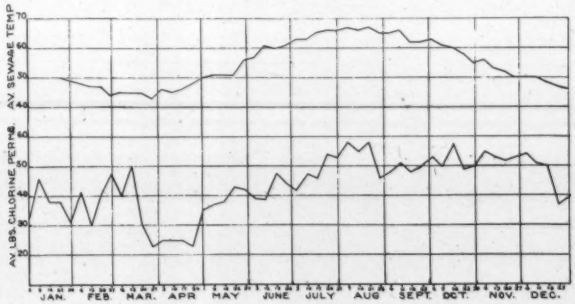


Fig. 1.—Sewage temperatures and chlorine demands, Sewage Treatment Plant, City of Norwalk, Conn. Taken from Weekly Reports of Operation for Calendar Year 1933.

age throughout the year 1933, with varying sewage temperatures, as observed by Mr. W. P. Petrie, superintendent of sewage treatment at Norwalk. The Norwalk sewer system is on the combined plan. Naturally, the chlorine demand does not vary with temperature alone; weaker sewage during the spring and other rainy periods, the surplus of chlo-

rine residual observed, and possibly other considerations, have a bearing on the quantity of chlorine used. However, the comparison shown is of interest. In some cases, higher sewage temperatures (72° F. and above) than indicated for Norwalk will promote the formation of hydrogen sulphide in the sewage, which is absent at lower temperatures, and consequently there may result a marked increase in chlorine demand with temperature rise.

TABLE II.—*Showing Effect of Chlorine Residuals and Detentions on Elimination of B. Coli in 0.01 cc.*

× = Samples in which *B. Coli* were present in 0.01 cc.
0 = Samples in which *B. Coli* were absent in 0.01 cc.

Chlorine Residuals, P.P.M.	Detentions in Minutes					
	1–3	5	10	15	30	60
+2.0	×					
1.5		0	×	0	0	
1.0	××	×	0×	×	0	
0.9	×	×	×	0		
0.8		×	00	×	00	
0.7			0×			
0.6	××	00	000	00	000	0
0.5		0	0	0×	0	
0.4	×	××0	××0000	0000	0000	
0.3	××	×××	×	×	00	
0.2		××	×000	000	00	
0.1				×0	×	
0.0–0.09					×00	0

EFFECT OF HYDROGEN SULPHIDE

Hydrogen sulphide in some Connecticut sewages has been found to vary from 0.5 to 10.0 p.p.m. In making field tests for hydrogen sul-

phide, the iodine titration method was found to be unreliable, but the Salle-Reinke [2] method, using antimony tartrate, gave very dependable results in the absence of interfering colors, when used with a home-made

TABLE III.—*Showing Effect of Chlorine Residuals and Detentions on Elimination of B. Coli in 0.1 cc.*

× = Samples in which *B. Coli* were present in 0.1 cc.
0 = Samples in which *B. Coli* were absent in 0.1 cc.

Chlorine Residuals, P.P.M.	Detentions in Minutes					
	1–3	5	10	15	30	60
+2.0	×					
1.5		×	×	×	0	
1.0	××	×	0×	×	0	
0.9	×	×	×	0		
0.8		×	×0	×	××	
0.7			×0			
0.6	××	××	××0	×0	000	×
0.5		×	×	×0	0	
0.4	×	×××	×××××0	××× 0	××00	
0.3	××	×××	×	×	×0	
0.2		××	×××0	××0	×0	
0.1				××	×	
0.0–0.09					××0	0

color comparator. The comparator was absolutely necessary for reading H_2S contents below 2.0 p.p.m.

In two or three instances, large amounts of hydrogen sulphide resulted from infiltration of sulphate-bearing sea water into the sewers. The sulphur-splitting organisms in the sewers and treatment tanks broke down the sulphates to produce sulphides. As much as 2,300 p.p.m. of sulphate has been found in samples of unpolluted sea water. Chloride determinations on certain Connecticut sewages have indicated 20 to 50 per cent of the sewage flow to be salt water during high tidal stages

Sometimes septic sewage has been found to contain high amounts of hydrogen sulphide, even in the absence of sea water infiltration. The chlorine demand shows a marked increase when the first trace of hydrogen sulphide appears and chlorination becomes unduly costly with

TABLE IV.—*Showing Effect of Chlorine Residuals and Detentions on Plate Counts for 24 Hrs. at 37° C.*

× = Samples in which plate counts were more than 100
0 = Samples in which plate counts were less than 100

Chlorine Residuals, P.P.M.	Detentions in Minutes					
	1–3	5	10	15	30	60
+2.0	×					
1.5		0		0	0	
1.0	××	×	×00	×	×	
0.9	×	×	×	0		
0.8		×	00	0	00	
0.7			××			
0.6	××	×0	×00	00	××0	0
0.5		×	×	×0	0	
0.4	×	××0	××××00	××00	0000	
0.3	××	×××	0	×	00	
0.2		××	××00	×00	×0	
0.1				××	×	
0.0–0.09					××0	×

Note: The bacteria counts on the four samples having a residual of 0.2 p.p.m. or greater, with 30 minutes detention, were all less than 500, even though greater than 100.

increasing H_2S content, because of the reaction $Cl_2 + H_2S = 2HCl + S$. Pre-chlorination of sewage markedly retards the formation of H_2S and with sufficiency of dosage will prevent it.

An example of the effect of the break-down of sulphates introduced into the sewage by the entrance of salt water at high tidal stages is

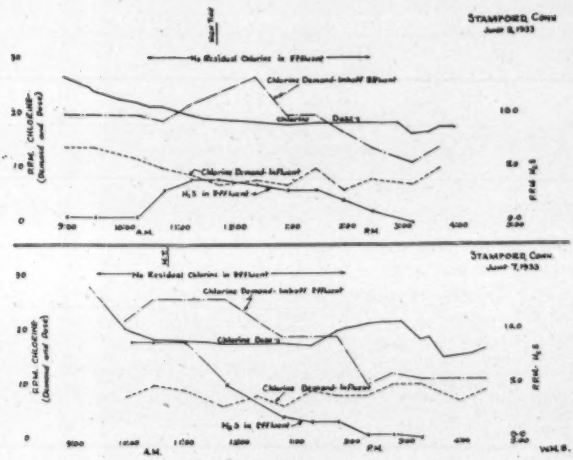


FIG. 2.—Effect of hydrogen sulphide on chlorine demand.

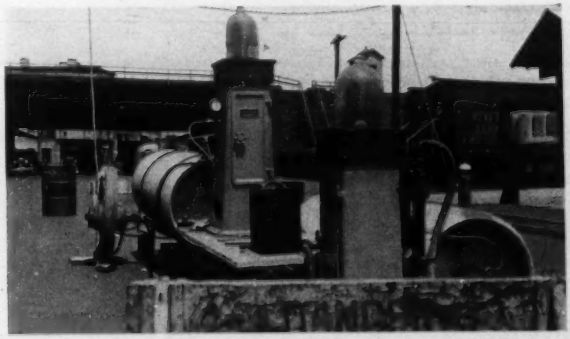


FIG. 3.—Pre-chlorination tests, Stamford, Conn., May 19, 1933. Conducted by Engineering Department, City of Stamford, the Chlorine Institute of New York City, and the Connecticut State Department of Health.

shown by the curves in Figure 2, illustrating tests on the Stamford sewage in 1933, made in coöperation with Mr. Willard S. Conlon, City Engineer, and Mr. W. M. Bingley of the Chlorine Institute. It is to be noted that the sulphate break-down did not occur until after the sewage had entered the Imhoff tanks where bacterial action was pronounced. Based on these observations pre-chlorination was adopted. A photograph of the pre-chlorination equipment at Stamford is shown in Figure 3.

Chlorine Demands on Different Sewages

Table V is presented to show some of the variations in chlorine demands of different sewages in Connecticut. The figures for chlorine demands and B.O.D.'s are only very approximate, because they may be influenced by changes in many of the factors mentioned in the early part of this paper. They do serve, however, to reveal information of interest. In each case, the term "chlorine demand" is somewhat loosely used to indicate the amount needed to produce a chlorine residual. The data in the table have been compiled from the latest information available to the writers.

Table V

Plant	Type of Plant	Pre or Post Chlorination	Ave. B.O.D. Raw Sewage, P.P.M.	Average Chlorine Demand Lbs. M.G.
† Mystic Oral School	Septic Tank	Pre	593	250
Cos Cob	" "	Post	173	109
East Portchester	" "	Post	413	167
East Portchester	" "	*Pre	413	210
Old Greenwich (former plant)	" "	Post	150	245
Old Greenwich (new plant)	Plain Sed.	Post	150	67
† Norwalk	" "	Post	140	45
New Haven	" "	Pre	155	65
Stamford	Imhoff	Post	305	150
Stamford	"	Pre	305	80
‡ Stratford	"	Post	115	100
‡ Stratford	"	*Pre	115	80
Grass Island, Greenwich	"	Post	215	107
West Haven	"	Post	475	200
† Laurel Heights Sana.	"	Pre	425	150
† Litchfield Junior Republic	Septic-Sand	Post	300	17
New Canaan	Activated sludge	Post	120	30
Litchfield	Sand Filters	Post	220	12

* Tried on experimental basis only.
† All year round chlorination. Other plants, summer only.
‡ Estimates of flow very approximate.

The data in this table are of interest in showing the advantage, in some instances, of pre-chlorinating, also the expectedly high chlorine demand of septic tank effluents.

Methods of Application of Chlorine

Sewage chlorination installations require as careful planning as do other features of plant design.

When the New Haven, Conn., plant was built, as late as 1929, there was some hesitancy, based on the very meagre information available, as to whether chlorine residuals sufficient to procure effective disinfection could be carried through the sedimentation tanks with pre-chlorination. However, the step was taken and it proved successful. Pre-chlorination at plants discharging chlorinated tank effluents frequently results in ironing out operating troubles caused by flow variations. Pre-chlorination also does away with the need for contact chambers, which require cleaning and maintenance as well as construction expense. It is, however, desirable in the case of a new plant, to provide arrangements so that chlorine may be added either before or after tank treatment—if not at both points. In plants employing secondary treatment, chlorination of the final effluent is the most desirable scheme to insure adequate disinfection at the least expense. Concurrently pre-chlorination may be employed (when needed) to correct odors or preserve the freshness of the sewage.

Enslow has pointed out that poor baffling and too sluggish flows in tanks may defeat the economy of pre-chlorination. Deep baffles or baffles close to tank inlets may cause the sewage flow to "dive" in the tanks, with unsatisfactory results.

Solution-feed application of chlorine to sewage is preferable to the dry-feed method. Better mixing of chlorine and sewage is usually effected. If dry-feed application is used, a submergence of at least 4 feet should be given to the chlorine diffuser, so that absorption may take place before the chlorine gas escapes to the atmosphere. One dry-feed installation at a Connecticut state institution works very satisfactorily. No water was available here. The use of sewage effluents in connection with solution feed chlorination has been employed in some instances outside of Connecticut.[3] The manner of distribution of chlorine solution to the sewage was found to be important at one state institution, where solution applied at the inlet produced very ineffective results until a distribution grid was substituted for an open-end hose.

Chlorinator houses should not ordinarily be built over chlorine contact chambers because of the possibility of damage from escaping chlorine. The house can usually be built adjacent to the chamber and the

chlorine solution hose or pipe can be carried down through the house floor and through the wall of the contact chamber. In many cases it is practical to pipe chlorine solution through hose lines for considerable distances.

Arrangements should be provided for removal of solids accumulating in contact chambers either by frequent hand stirring so as to discharge them with the effluent or by drawing down the chamber. Operating contact periods may not agree with theoretically planned contact periods unless the contact chamber is properly baffled.

Where pre-chlorination is inaugurated ahead of settling tanks that have been in use for some time without pre-chlorination, it may require several days or even weeks of operation, with very high chlorine doses, before the chlorine demand of the solids on the side walls and elsewhere in the tanks become satisfied and normal operating conditions are established. This is particularly true with Imhoff tanks.

Where rates of sewage flow do not vary greatly throughout the 24 hours, it may be possible to set one rate of chlorine dosage to care for the maximum flow rate and consequently to over-chlorinate during the remaining periods. Even where flow rates vary considerably, particularly in small plants, it will usually be desirable for practical reasons to follow the procedure of employing a constant rate of chlorine dosage. Chlorinators equipped to apply chlorine in proportion to the flow have not always functioned satisfactorily. Where a Venturi tube is available, the Venturi-operated, automatic chlorinators have proved to be practical means of proportioning the chlorine dosage. In some plants, and particularly in large plants, it may pay to make frequent manual adjustments of the rate of chlorine dosage. The resulting saving in cost of chlorination may pay for the necessary supervision, as against setting the chlorine dosage to care for maximum rates of flow.

Disinfection of Harbor Water

A striking illustration of the protection of bathing beaches and shellfish areas by sewage chlorination is afforded by a study made in one of our large harbors in the year 1932. Bathing beaches and oyster growing areas exist in this vicinity. The sewage from the city, with an average yearly flow of about 5 m.g.d., is treated by fine screening, sedimentation and post chlorination. The point of discharge is into the river entering the harbor at a distance of approximately two miles from the areas of sampling.

During the period of study there were two interruptions of sewage chlorination because of difficulties which have since been largely overcome. Moreover, disinfection was purposely discontinued for observa-

tion during one time of the year when neither the bathing beaches nor shellfish areas would be adversely affected. The other treatment processes—screening and sedimentation—were functioning during these periods of cessation of chlorination.

Table VI illustrates conditions with and without chlorination.

TABLE VI

Chlorination in effect?	Water Samples					Shellfish Samples			
	Total no. samples	*B. Coli* +in 0.1 and 1 c.c.	*B. Coli* +in 1 c.c. but absent in 0.1c.c.	*B. Coli* +in 10 c.c. but absent in 1 c.c.	*B. Coli* absent in 10 c.c.	Total no. samples	Scores 140 or up	Scores 14–50	Scores 5 or less
Yes.....	349	3 (1)*	24 (7)	119 (34)	203 (58)	66	0 (0)	13 (20)	53 (80)
No.....	249	29 (12)	86 (35)	70 (28)	64 (25)	40	11 (27.5)	11 (27.5)	18 (45)

* Figures in brackets indicate per cent of samples examined which fell under the classification indicated.

Although no definite standards of bacterial quality for seawater overlying shellfish areas have been adopted, it is generally conceded that where such waters carry sufficient contamination to cause 50 per cent or thereabouts of the samples to show *B. Coli* in 1 c.c., the area is questionable. Oyster scores (*B. Coli* content of the shell liquor) may be affected by pollution and temperature and are not of themselves a criterion of safety of growing areas. However, scores over 50 are considered objectionable. It is to be noted that whereas 47 per cent of water samples in this area showed *B. Coli* in 1 c.c. without sewage chlorination, only 8 per cent fell in this classification with chlorination. Moreover, 27.5 per cent of oyster samples scored higher than 50 when there was no sewage chlorination as against 0 per cent with chlorination.

Because of the possibilities of interruption of chlorination and the existence of some storm water overflows in the area, the shellfish area, previously closed against harvesting of market shellfish, was not unrestrictedly opened as the result of chlorination, but a great economic saving was effected by allowing the harvesting of oysters from this area during periods when continuous water temperatures recorded were

below 41° F. Under such low temperatures, oysters are almost free from pollution because of their hibernating proclivities and therefore chlorination constitutes an added safeguard. Bathing areas in the outlying waters in the vicinity are considered to be fairly well protected by the chlorine disinfection.

References

1. Scott and Pool: *Eng. News Record*, Dec. 29, 1927.
2. H. E. Johnson: THIS JOURNAL, 3, April, 1931.
3. C. H. Vivian: *Water Works & Sewerage*, Jan., 1934.

TIPPING BUCKET SLUDGE METER DEVELOPED AT AURORA, ILLINOIS

By Walter A. Sperry

Superintendent, Aurora Sanitary District, Aurora, Illinois

The Aurora, Illinois, sewage treatment plant as completed in 1929 did not include any provisions for the metering of sludge from the Dorr clarifiers to the digesters. One single-cylinder, ball valve, diaphragm pump located at the clarifier level discharged sludge from either of the four clarifiers to either of the three digesters through 4-inch pipe lines. The location of pump and piping was such as to make impractical the "cutting in" of any diaphragm or venturi type meter without a very undesirable rearrangement of the piping. The 40-gallon per minute discharge of the pump produced pipe line velocities too low for trustworthy results from such meters. Under operating conditions this arrangement was quite unsatisfactory. The pump discharge varied with the per cent solids contained in the sludge. The sludge flow was not visible; how often and how long to pump sludge, therefore, could only be approximated. Samples for daily routine analysis were not sufficiently representative. The detection of clogged valves depended upon the alertness and hearing of the operator.

Since it was essential to know the quantity of sludge delivered to the digesters, the flow was approximated by assuming an average pump rate of 40 gallons per minute. The pumping time per day was recorded in minutes and the per cent solids in the sludge was determined from a daily composite sample collected from the beginning, end and middle of each pumping period. From this the pounds of dry material delivered to the digesters was computed by the use of the following formula:

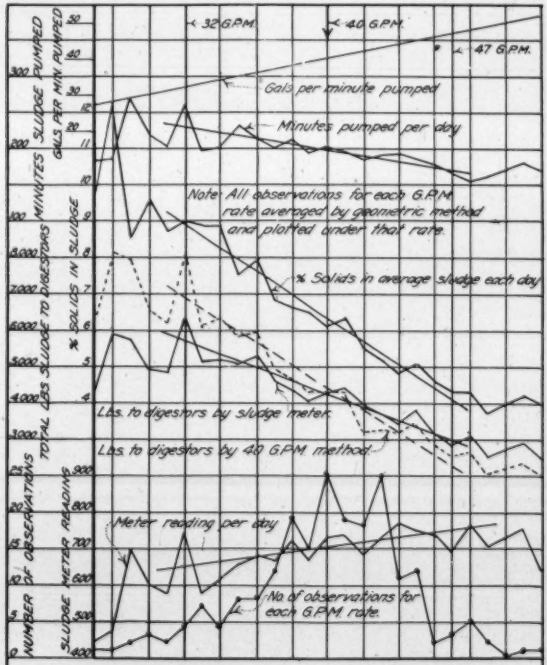
$$\frac{\text{Minutes pumped} \times 40}{7.5} \times 62.5 \times \% \text{ Solids} \times \text{Sp. Gravity of Sludge.}$$

40. = Gallons per minute assumed for pump.
7.5 = Gallons in one cubic foot.
62.5 = Pounds water in one cubic foot.

While this method of procedure eventually proved to be fairly satisfactory there was still much to be desired and no form of meter known to us, now on the market, seemed applicable to our set-up.

The use of a fill-and-draw tank system was objectionable due to the necessary size and weight of such a tank, as well as the problem of cleanliness and odor involved. This led to a consideration of a tipping bucket originally suggested to us by Mr. C. R. Velzey. This type of

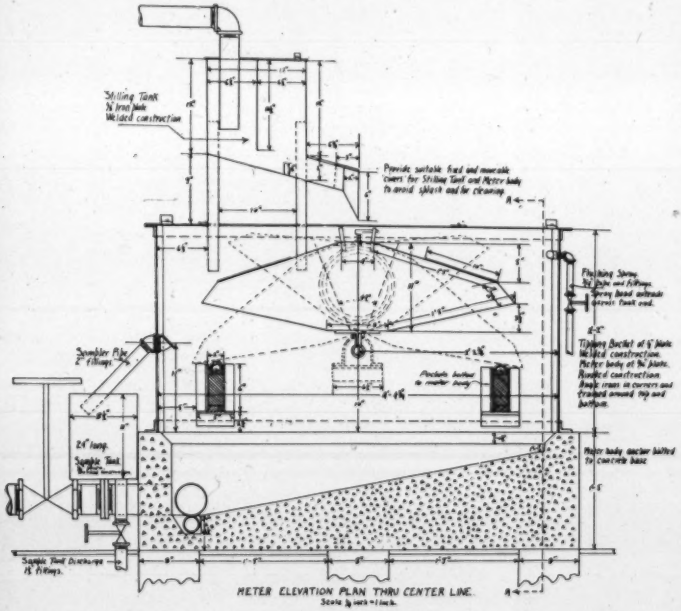
meter had the advantage of giving a positive volume measurement equivalent to the fill-and-draw tank system, with complete visibility of the flow, independence of pipe line velocities and the opportunity to sample satisfactorily.


32 G.P.M.
40 G.P.M.
47 G.P.M.
Gals per minute pumped
Minutes pumped per day
Note: All observations for each G.P.M. rate averaged by geometric method and plotted under that rate.
% Solids in average sludge each day
Lbs. to digestors by sludge meter.
Lbs. to digestors by 40 G.P.M. method.
Meter reading per day
No. of observations for each G.P.M. rate.
NUMBER OF OBSERVATIONS
TOTAL LBS SLUDGE TO DIGESTORS
% SOLIDS IN SLUDGE
MINUTES
SLUDGE METER READING
GALS PER MIN PUMPED
SLUDGE PUMPED

COMPOSITE CURVES FOR JUNE 1 - DEC. 31 COMPARING "SLUDGE METER" VERSUS "40 G.P.M." METHOD OF DETERMINING LBS. OF SLUDGE DELIVERED TO DIGESTORS.

This meter, as the drawing indicates, consists of three parts, the meter itself; a permanent calibration tank and an automatic sludge sampling device. The entire apparatus was constructed by plant employees in the plant shop for a cost (labor excluded) of approximately $100. It rests on the roof of the digester and receives sludge from the pump into an open stilling tank of such design as to quiet the flow and deliver it as a thin sheet to the bucket.

The bucket delivers the sludge to the concrete receiving pan from which it is discharged to either of the three digesters. When desired, a stated number of buckets can be discharged to the outside calibration tank, which provides an accurate means of determining the volume delivered, approximating 0.75 cu. ft. per side per dump.



The sampling device consists of a tank and drain communicating with the interior of the meter through a pipe and two reversed 45° ells and so arranged that for each bucket cycle about 100 c.c. are thrown through to the sampling tank. Since the bucket tips approximately once every 11 seconds, three to four samples per minute are collected throughout a given pumping period. This aliquot part is thoroughly mixed and an appropriate sample collected into the laboratory bucket. The number of bucket tips is recorded on a lever operated counting device.

In general the construction of the meter is so simple and sturdy that the notes contained on the accompanying drawing sufficiently describe

it. Any plant superintendent could easily adapt this design to his local situation. It should be noted that the Hyatt roller bearings used on the bucket pivots have been found unsatisfactory and a plain brass bearing works quite as well.

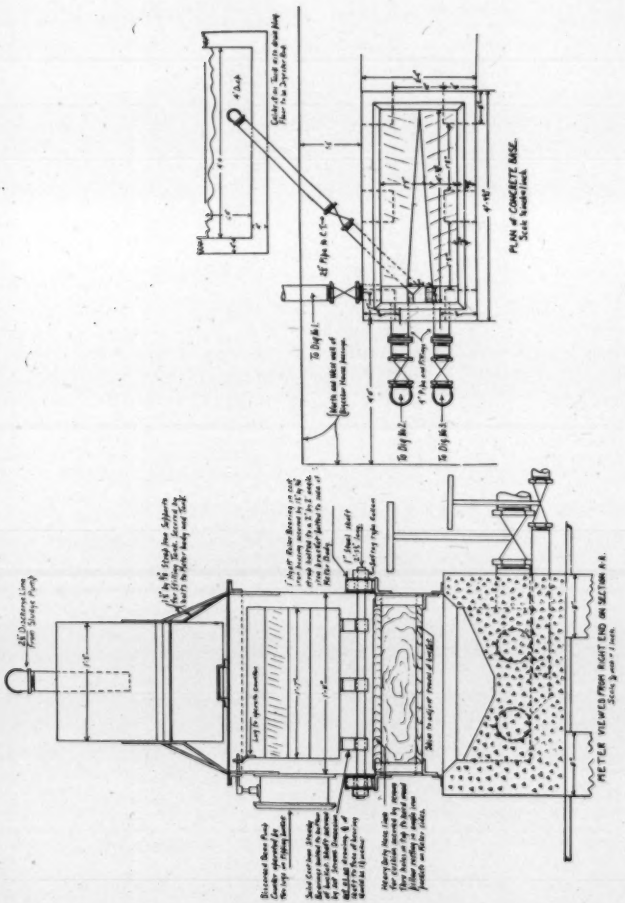
In regular use the operator is instructed to pump sludge as long as sludge flow continues, taking care to record the time of pumpings. Record is made of the number of meter tips and the total time of pumping per day. Once each week the bucket is calibrated. For the period June 1 to December 31, 1933, this calibration averaged 1.48 cubic feet per bucket cycle as follows:

Calibration of Bucket, Average Monthly Results, 1933, in Cubic Feet

June	1.54	September	1.47
July	1.49	October	1.45
August	1.43	November	1.49
December	1.49		

This apparatus was placed in operation May 18, 1933. From June 1 to December 31 a careful daily record was kept of the exact performance of this apparatus in parallel with the "40 G.P.M." formula named above. The results of this 214-day study are shown in composite form on the accompanying set of curves. All readings occurring within the 214-day period were averaged by the geometric method and plotted under the appropriate "gallon per minute" rate. When thus arranged it was evident that the relations between "minutes pumped," "per cent solids," "pounds delivered to the digesters" and "meter readings" all bore straight-line relations to gallons per minute delivered. The straight averaging line for each set of observations was calculated by the approximate method of least squares. The average weight of sludge delivered to the digesters by the meter checks exactly with the pump record for the 25 times the pump actually worked at 40 g.p.m. For rates lower than 40 g.p.m. the meter rate drops below the pump rate. Also note the interesting relations between time, per cent solids, and pump delivery. Likewise, the pounds delivered is directly related to the per cent solids present, as would be expected.

The meter records also indicated that whereas the daily pump performance varied considerably the monthly average was within 3 gallons, plus or minus the 40 g.p.m., ranging from 37 as a monthly average for July to 42 as a monthly average for August. This explains the reason for the fairly dependable results obtained when no meter was used. For the 214-day period under study:


PLAN of CONCRETE BASE.
METER VIEWED FROM RIGHT END ON SECTION A-B.

Average solids in sludge	6.7	per ct.
Average meter calibration	1.48	cu. ft.
Average minutes pumped	193.	
Average meter reading, complete cycles	674.	
Average pounds by sludge meter delivered to digesters	4,220	per day.
Average pounds by 40 g.p.m. meter delivered to digesters	4,630	per day.
Sludge meter delivered 8.8% less than "40 g.m.p." method		
Average gallons per minute delivered by pump	40.	

The dependable performance of this device indicates that this method of measuring sludge is a most desirable one. It possesses the following advantages:

(*a*) It provides an accurate and continuously representative sample of the sludge delivered to the digesters.

(*b*) The flow of sludge is visible at all time, giving immediate notice should the flow be interrupted by clogged valves. As the curves indicate, this visible flow of sludge demonstrates the day by day inaccuracies of the pump rating method, due to the speeding up and slowing down of the pump as the sludge is thick or thin.

(*c*) Under this method there is no arbitrary limit to the time of pumping sludge at any one period. The time of pumping being recorded, the period of pumping can be extended until the clarifier "blanket" is removed.

(*d*) A dependable, accurate volume measurement of the sludge is obtained. This, together with the per cent solids from the more representative sludge samples now possible, provides data for more accurate computations of equivalent dry material delivered.

(*e*) The meter makes possible a rearrangement of the schedule of delivery to the digesters so that the exact quality and quantity of sludge being delivered to each digester can be noted at the close of each month for use in more accurate computations of sludge invoice.

(*f*) The apparatus is mechanically simple with nothing to get out of order. It is easily kept clean and free from odor or unsightliness.

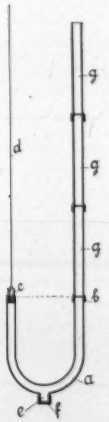
(*g*) The calibration arrangement is such that but little time is required. Calibrations can be made as frequently as desired.

A SIMPLE DEVICE FOR SAMPLING SLUDGE

By Dr. H. Bach

Chief Chemist, Emschergenossenschaft, Essen

The sampling of sludge from various depths in deep containers, especially in digestion tanks, often proves necessary in the course of investigations concerned with the control of digestion. Various types of collectors are used for this purpose, such as boxes fitted with complicated arrangements of rods, taps and springs, to insure collection of the sample at the desired depth. Such collectors, apart from being expensive, are mostly unreliable and difficult in handling. I have therefore been led to design a simplified device, schematically drawn in Fig. 1.



The U-shaped pipe *a* of aluminum, brass or other suitable metal, 2½ to 3 in. diameter, bears on the top of one leg a thread *b* which fits a set of pipe sections *g*, of uniform length, thus forming a pipe long enough to reach the desired depth of the tank.

The mouth of the other leg of the U-pipe, *i.e.*, the sludge inlet, is fitted with a wooden stopper *c* which can be removed by means of the cord *d*. The bottom of the bent pipe opens into an outlet on which is screwed the cap *f*.

For sampling sludge in a tank, insert the stopper *c* and close the cap *f*, push the apparatus vertically down in the sludge, using the cord *d*

as a yardstick, until the sludge inlet reaches the desired depth. Then pull the cord thus opening the inlet. The sludge enters the pipe and rises in it to the level of the sludge in the tank. Now hoist the apparatus vertically, the sludge inlet remaining open. On the way to the surface the sludge flows out of the shorter leg of the pipe under the pressure in the longer leg, so that sludge from the strata higher than the sampling point cannot enter the pipe. The desired sample of sludge remains in both legs of the piece *a*, from which it may be transferred to a container by unscrewing the cap *f*.

Editorial

THE DEARBORN PLANT

Probably no sewage treatment works in the United States during the past two years has received the publicity accorded the Dearborn, Michigan, plant. The Laughlin process of chemical-mechanical treatment has been discussed and described so often that no further outline of its procedure is required in these comments. The Dearborn West Side plant, however, is subject to such unusual operating conditions that a discussion of Mr. Owen's very interesting article, on page 742 of this issue, may not be amiss. Some of the data in Mr. Owen's paper repeat, but augment, those reported by Mr. Zack in THIS JOURNAL for May, 1933, page 458. However, a little repetition of data reported at an earlier date was considered advisable in order to round out the two years of operation of the Dearborn plant.

The revival of interest in chemical treatment of sewage has focussed attention on the Dearborn plant. Those concerned with the application of chemical treatment for their own sewage treatment problem have hoped to obtain, from the Dearborn records, data that might be applied to other sewages in evaluating the degree and cost of treatment. The Dearborn records, however, are somewhat disappointing for application to other problems, for several reasons, the main one being the fact that, for most of the two years' period of operation, sludge from the East Side sedimentation plant has been mixed with West Side sewage, and the mixture, representing a sewage of different character and far more concentrated than normal sewage, has been treated with chemicals and settled. The use of such large amounts of pre-settled solids has introduced variable factors not characteristic of normal sewage, particularly with reference to the percentage removal of suspended solids and B.O.D. For example, the results given by Mr. Owen in Table VII indicate a reduction of 88 to 92 per cent of the B.O.D. during the first three periods of operation, from May, 1932, through October, 1933. During these periods sludge from the East Side plant was mixed and treated with West Side sewage. The last period, from Nov. 1933 through April, 1934, is claimed to be typical of treatment of sewage alone, showing a reduction of 78 per cent of the B.O.D., and in Table VIII this is further increased to 85 per cent by elimination of results held to be inferior because of inclusion of an abnormal amount of filtrate from the filtration of East Side sludge, as well as floor and sump drainage.

The inclusion of suspended solids data in Table VIII, however, indicates that the results held to be typical of normal sewage are still based on some influents decidedly abnormal with respect to suspended solids. The high removals of B.O.D. almost invariably occur on days when suspended solids were excessively high, ranging from 400 to 1300 p.p.m. The data in Fig. 2 are presented to show that the percentage removal of B.O.D. increases with increasing strength of influent, which is of course true in any type of sewage treatment, but it is surprising to note that the points plotted in the lower curve actually show a lower B.O.D. in the effluent, in parts per million, with concentrated sewages (200 to 300 p.p.m.) than with weak (100 to 200). If the curve were drawn through the most probable locus, it would indicate a *decrease* in B.O.D. of the effluent from the more concentrated sewages. This would hardly be expected with a normal sewage, in which an increasing influent B.O.D. would result in an increasing effluent B.O.D., in parts per million. In the Dearborn sewage, high B.O.D. values are in general due to presettled solids, not colloidal or dissolved solids, consequently high removals of B.O.D. are obtained, which might not be possible with normal sewage. Apparently, therefore, the West Side sewage at Dearborn was abnormal under conditions of flow and operation reported in Period 4, due to storage and settling of suspended solids in the interceptor during the 7 to 10 hours per day during which no sewage was treated. A larger flow, continuous operation and continuous pump-down of the interceptor would provide conditions more representative of normal operating practice elsewhere.

Mr. Owen has observed that the Dearborn plant produced an effluent averaging around 20 p.p.m. B.O.D. for the 85 days shown in Fig. 2, no matter what the B.O.D. of the influent, which averaged 130 p.p.m., but in the experimental plant at Coney Island, the B.O.D. of the effluent was 41 p.p.m., from an influent containing 132 p.p.m., almost identical with the Dearborn influent. Moreover, the Coney Island tests included the use of a very large amount of lime (900 lb. per m.g.) albeit a lower usage of ferric chloride (161 lb. per m.g.) than was used at Dearborn.

The general tenor of the discussion thus far is that the percentage of B.O.D. reduction may be assumed to increase with increasing strength of influent, but that caution is advisable before concluding that the effluent B.O.D. can be reduced to around 20 p.p.m. with all types of sewages of low or average concentration.

The use of ferric chloride increased materially in Period 4, and this increase is undoubtedly responsible in large measure for the increase of B.O.D. reduction to 78 per cent in Period 4, as compared with reductions of 75 per cent reported for November, 1933, by Dr. Buswell, and 66 per cent reported by Mr. Zack for 26 days in 1932 when neither sludge nor excessive suspended solids were present in the sewage.

With regard to operating costs, the Dearborn data are not of much general significance, since Mr. Owen states that because the West Side plant serves as the point of disposal for East Side Plant sludge, the problem of quoting operating costs in terms of dollars per million gallons is indeed complicated, if not impossible.

Although it appears that conclusions should be reserved concerning the removals of B.O.D. and cost of treatment of other sewages as based on the Dearborn records to date, Mr. Owen presents a detailed record of what the Laughlin process has accomplished at Dearborn. The rates of filtration of sludge on the Oliver filters have been greatly increased; the degree of purification has been stepped up by more careful control of coagulation, larger use of chemicals, and elimination of sludge filtrate in the sewage treated.

Improvements are planned at Dearborn which may result in decrease of use of chemicals by more efficient flocculation; more adequate flow of sewage will give a better percentage loading of the plant, as compared with the design capacities; and disposal of sludge by incineration, if successful, should dispel any doubts concerning the undesirability or inadequacy of the present Dearborn procedure of dumping filter cake containing undigested sewage solids. The data from Dearborn show a surprisingly high degree of purification as compared with the degree of treatment expected from or ascribed to chemical treatment four decades and more ago, and even though the range of 75 to 80 per cent reduction of B.O.D., with 20 to 25 p.p.m. in the effluent, may not be possible with other sewages, or even with Dearborn sewage of normal characteristics, yet the degree of treatment may be ample for disposal situations where the highest practicable degree of treatment, ranging up to more than 90 per cent, is not demanded.

In view of the pioneering nature of the Dearborn plant, and the many problems that have had to be overcome and still must be solved to bring it to its maximum efficiency, Mr. Owen is to be congratulated on the record to date, and urged to follow up this two-year report by future reports of equal interest and value.

F. W. M.

GEORGE W. FULLER

Many of the readers of THIS JOURNAL knew George W. Fuller personally and all of them knew of him professionally. The news of his death June 15, 1934, was a shock to his many friends and his passing leaves a feeling of personal loss to those who knew him well.

Mr. Fuller, who was sixty-five years old, had been in fair health until a few days before his death. He had been quite active during the past

two or more years, and seemed to have recovered fully from his serious illness of several years ago. Because of his great interest in professional activities, he took an active part in societies, meetings and professional contacts up until the week of his death, and therefore his absence will be felt more deeply than if he had retired years ago. He was a man, however, who would never have been satisfied to lose contact with the daily affairs of his busy life, and to those who knew him there is a feeling of thankfulness that he died in the midst of an active and helpful career.

Mr. Fuller was honored so often, for the great part that he played in the development of sanitation in America and abroad, that no detailed recitation of his honors is necessary. He was known internationally for his books on sewage treatment, reflecting his experience from the early days of the Lawrence Experiment Station, which he directed from 1893 to 1895, following his graduation from the Massachusetts Institute of Technology in 1890 and his subsequent post-graduate work in Berlin. The famous and pioneering Louisville tests on purification of water next engaged his attention, the results of which are still referred to as one of the epochal steps in the development of water purification.

Since 1899 Mr. Fuller has been in consulting practice in New York City. His fame as a consultant in sewage treatment is attested by many of the important sewage treatment works in the United States, culminating in the design and, at present, partial completion of the Ward's Island activated-sludge plant for New York City. One of the outstanding achievements of his later life was the chairmanship of the Engineering Board of Review of the Sanitary District of Chicago, which reviewed the complicated problem of sewage treatment and lake water diversion for the Sanitary District. Mr. Fuller welded the, in some cases, divergent opinions and conclusions of these 28 eminent engineers into a harmonious and unanimous report. This required all of the tact, judgment and ability for which he was noted. His outstanding service as Chairman of this Board will long be remembered by his colleagues and appreciated by the Sanitary District.

Mr. Fuller was a leader for so long in the field of sewage treatment that his passing will be deeply felt. Undoubtedly he will be missed most poignantly (except for his immediate family) by the members of his firm, and to them the sincerest sympathy of their professional colleagues is extended.

F. W. M.

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

SIXTH ANNUAL SPRING CONFERENCE

Yosemite Park, May 25–26, 1934

MORNING SESSION, MAY 25, 1934

Members and guests of the California Sewage Works Association assembled at the Camp Curry headquarters at 8 A.M. and proceeded in small groups to the activated sludge Sewage Treatment Plant on the south side of the Valley near Bridal Veil Falls. Inspection of the plant, laboratory and records was under the direction of the local arrangements committee, consisting of H. B. Hommon and E. M. Hilton. A caravan was formed at the plant and conducted on a trip through the Valley, stopping at a CCC camp, visiting automobile and housekeeping camps and inspecting the incinerator, can-baling machine and equipment for washing garbage cans.

Informal groups met together at lunch.

AFTERNOON SESSION, MAY 25, 1934

The meeting was called to order by President McMillan who introduced Harry B. Hommon as the man primarily responsible for our meeting in Yosemite. He introduced the Park Superintendent, Colonel C. G. Thomson, who welcomed the Association to the Valley, and told a few of his experiences in oriental countries, particularly the Philippine Islands, and the constant watchfulness needed to safeguard health in those countries. The work of Harry Hommon and his associates in the Public Health Service is greatly appreciated by the Park Service.

Proceeding with the regular business, President McMillan first called attention to the fact that A. M. Rawn had arranged for the papers to be presented.

A. W. Wyman read a paper entitled "Handling of Flood Waters at a Disposal Plant," with comments on the need for grit basins. The New Year's storm, the heaviest in 50 years, resulted in an increase of flow from 8 m.g.d. to 25 m.g.d. with complications, including deposit of sand in aerating units, and reduction of nitrogen content in fertilizer. A grit chamber would be a great asset during heavy storm periods. Harold F. Gray, in discussion, called attention to the economics of storm sewer design, the arbitrary assumption of capacities, and the need for

data on storm damage. Such data should, he stated, be available on the storm referred to in Wyman's paper. A. M. Rawn drew attention to the need of definitions, separate sewers being not actually separate when storm flows increase normal sanitary flow threefold. R. R. Ribal gave experiences in Oakland where storm sewers are overloaded. Colonel Smith of Los Angeles reported the practice of cross-connecting storm and sanitary lines when numerous bond issues for relief sewers were turned down. The only alternative is to let lines fill up and sewage run down the streets. Prof. C. G. Hyde suggested discussion, at a future convention, of the whole subject of ventilating manholes. T. F. Eastman and H. B. Hommon also discussed the paper before time was called by the President.

R. F. Goudey read a paper entitled "Patented Ideas for Sewage Disposal," in which he brought out the fact that nearly every device used in sewage disposal works is or has been patented. Patents have dominated all other lines of engineering endeavor and must be recognized in the field of sewage disposal. Goudey reviewed the patent situation comprehensively and pointed out the need for engineers and operators to circumvent patents and avoid infringement. Alva J. Smith asked where the engineering profession was drifting. If all devices and improvements are patented, he asked, are sanitary engineers simply to select the patented device they think best to submit to the Council of the city and will a battle rage between patents before the City Council? A. M. Kivari of the Dorr Company congratulated Goudey on his presentation of the subject. Kivari explained the status of patents in other commercial and industrial fields and stated that if experts on research are to be hired, the investment must be protected by taking out patents on ideas developed. W. A. Allen suggested that consulting engineers should apply patents to better advantage. C. C. Kennedy emphasized the distinction between "Process Patents" and "Mechanism Patents" and said the former involved royalties or percentages and nearly always political conditions which we should try to avoid. He favored mechanism patents to which he thought there could be no objection. G. S. Backus of the Oliver Filter Company said he thought Kennedy referred to "Royalty Patents" and "Apparatus Patents" and referred further to the research necessary to develop a process which could only be protected by a royalty patent. J. F. Smith of the Great Western Electro-Chemical Company agreed with Kennedy in favoring equipment patent. His company owns many process patents but where cities take open bids, it is difficult to include royalties in bid prices. He thought there was a justification for royalties but it was almost impossible to collect them.

The next paper read was "Slime Growths in Sewers," by F. E. De-

Martini. A general discussion of the more common fungi including *cladothrix, sphaerotilus, leptomitus* and *beggiatoa* was given describing their appearance and growth habits. Occurrence of these organisms has been reported at sewage disposal works at Dunsmuir, Roseville, Shastina, Yosemite; Choteau, Montana; Sparks, Nevada; and along Auburn Ravine below Lincoln, Linda Creek below Roseville, Santa Maria River below Guadalupe, Truckee River below Floriston, Mokelumne River below Lodi, Kings River below Reedley. Sewage and wastes containing carbohydrates, including milk plants, peach canneries, wineries, beet sugar plants, were contributing factors. Use of copper sulphate, lime and hydrochlorite solutions has been tried with varying success.

Professor Hyde, in discussion, referred to slime trouble at Westborough, Massachusetts, in 1899, and described in considerable detail the effect of paper mill wastes on the Truckee River below Floriston, *sphaerotilus* being the predominating organism. C. C. Kennedy also discussed the paper and referred to the high water consumption and dilute sewage, at most of the places reported as having slime growth. At Sparks, Nevada, for example, the B.O.D. was less than 100 p.p.m. and slime growths plentiful, whereas at Reno, Nevada, with the same water source, the sewage was stronger, B.O.D. about 275 p.p.m. and there are no slime growths. R. C. White of Yosemite reported growths in the sewer system. Sewage is dilute and cold with average temperature of 47 to 50° F. Use of chlorine at the head of the system loosened growth and allowed it to be collected at the grit chamber. The most serious effect of the growths is to increase screenings at bar screens. However, its presence does not improve appearance of aeration tanks and final clarifiers. W. T. Knowlton reported similar growths near Los Angeles in ditches containing waste water from moving picture plants, sewage or sulphur ingredients. R. C. Pomeroy asked the meaning of the term "carbonaceous." DeMartini answered that he meant chiefly carbohydrates such for example as beet sugar plant wastes.

The next discussion was on the general subject of P.W.A. and C.W.A. projects.

C. M. Hoskinson of Sacramento described a successful group of projects under his direction including grading and re-fencing, replacing curbs and gutters, investigation of sanitation basins, installation of sprinkling system, refinishing interior of filter house and pumping station and repainting. No sewer work was undertaken.

R. R. Ribal of Oakland gave a detailed discussion of relief work done by that city. His conclusions were that the construction of sewers by relief workers is economically sound but grading projects are not. Unemployment relief in Oakland accomplished more per dollar than C.W.A. on sewer construction.

T. D. Bowlus of Los Angeles County Sanitation Districts described a project of sewer construction, estimated cost $80,000. The districts furnished pipe, supervision and timekeeping. A trencher and back filler were employed because of approaching winter. Cost by hand was 16 times greater than by machine and men did not feel they were accomplishing anything when machine was not on the job.

W. A. Allen of Pasadena told of an experience in protection of banks of wash near the sewage disposal plant. A project costing $20,000 could have been done by machine for $1,000. The city placed a barrier on part of the bank and that part withstood storm flows, but the unprotected part went out during storms.

A short statement by W. F. Foster of Los Angeles County was read by Bowlus. Seven projects, involving construction of 125 miles of sewer, were described. Five thousand men were used, all work being done by hand. In spite of inexperience, delay by floods and constantly changing labor, over 50 miles of sewer were completed and ready for use when the C.W.A. was closed.

In discussion, President McMillan told of his experience in Ventura where only grading projects were approved, and therefore no storm sewers could be constructed. He asked if other cities had similar experiences.

A. M. Rawn suggested that many of the difficulties were probably due to a misunderstanding of the purpose of C.W.A. Jobs of short duration were completed but many projects were left unfinished because they were too large. Ribal stated that in Oakland so much money had been spent for relief before C.W.A. was started that no funds were available for purchase of materials even though projects were approved by C.W.A.

J. C. Albers reported eight projects on roads and fire motor ways.

F. M. Hilton of Yosemite reported use of C.W.A. labor on a variety of construction and maintenance projects. Men obtained were of high type and among them several were chosen to do technical work.

M. R. Bowen of Whittier reported good work with C.W.A. forces. All sewer jobs were completed and as high as 30 per cent for material was obtained in some cases.

Mr. Miller read a brief statement prepared by City Engineer Byxbee of Palo Alto, describing experiences with a P.W.A. project on sewage disposal.

The meeting adjourned at 5 P.M.

Dinner Meeting

A group of 116 members and guests assembled in the Camp Curry dining room for dinner. Following the dinner short talks were made

by President McMillan; Park Superintendent, C. G. Thomson; Park Engineer, E. M. Hilton; and Professor Hyde. Professor L. B. Reynolds read the report of the committee on award and recommended:

1. That the Award of Merit for the year 1933 be made to the Yosemite Plant.

2. That honorable mention be made to the Escondido Plant.

President McMillan presented the plaque donated annually by Wallace & Tiernan Company, to Col. Thomson, who accepted with thanks and passed the plaque on to Park Engineer Hilton.

Morning Session, May 26, 1934

R. D. Pomeroy, Research Chemist, Los Angeles County Sanitation Districts, read a paper on "Oxidation Potential Theory Applied to Sewage." He outlined the theory of oxidation-reduction reactions, giving illustrations commonly known to sewage works operators. A cell was constructed consisting of a solution of septic sewage and one of aerated water with copper plates for electrodes, and used to operate a delicate motor. The septic sewage was then aerated and after equilibrium was established, the motor stopped. While the energy available from sewage is large, it does not appear practicable to recover power. A measure of oxidation potential may be made in a manner similar to the determination of pH. Methylene blue is a commonly known indicator of oxidation potential. Dyes are also available for the determination but more data are needed to determine their ranges.

E. A. Reinke expressed appreciation for the paper which, though quite technical, gave promise of valuable information for future use. Alva J. Smith stated the contents of the paper were excellently prepared and throw light on things we need to know about our work. A. C. Beyer stressed the need for a distinction between oxidation-potential and B.O.D. just as we distinguish between pH and total acidity.

A discussion of Alva J. Smith's paper on "Utilization of Sewage Gas" was started by J. F. Byxbee. He summarized results reported by Walraven at the Springfield, Illinois, Sanitary District, and noted operations at Birmingham, England, Berlin, Germany, and Newark, New York. He also quoted from papers by Glenn D. Holmes and A. P. Banta, explaining their experiences with use of sludge gas. He concluded that there appeared to be no insurmountable difficulties in using sludge gas and gave data to show estimated savings from its proposed use at Palo Alto.

M. L. Crist stated reports he had obtained from various sources indicated power could be developed at a cost of one to one and one-half cents per K.W.H. including interest and depreciation. He reported a Ford engine operated three or four months at Salinas on sludge gas, showed no apparent deterioration of running parts.

F. S. Currie reported his only experience with use of sludge gas was at the San Bernardino plant. A 40 H.P. gas engine was operated continuously for eight months but when the Edison Company gave a low power rate with high standby charge, its use was abandoned and it has only been run off and on for the past five years. It is now proposed to use the gas for killing dogs and also to fuel an animal incinerator.

A. P. Banta discussed his experiences with use of gas at the Los Angeles County Sanitation Districts. Variations in composition and effect of hydrogen sulphide must be considered in gas utilization.

After a five-minute recess, Professor C. G. Hyde gave a talk on his trips east during the past four years. He described briefly the activities of the Federation of Sewage Works Association and the meetings of the Board of Control. Newer developments in the field of sewage disposal include various systems of chemical treatment, incineration of sludge and spray drying of sludge. There is a lively interest in sewage disposal problems throughout the country.

Weather conditions forced the cancellation of the outdoor barbecue at Glacier Point. An indoor barbecue around the fireplace at Camp Curry was attended by 45 members and guests. Mrs. Curry welcomed the members to the Valley. D. M. Tresidder, President of the Yosemite Park and Curry Company, entertained with a series of legends of the Yosemite Indians. Park Naturalist, Bert Harwell, and his rangers entertained with whistling and song numbers, until time for the fire fall and the feeding of the bears.

On Sunday a group of members visited the Hetch Hetchy sewage disposal plant and the Camp at O'Shaughnessy Dam.

E. A. Reinke, *Secretary*

THE MARYLAND-DELAWARE WATER AND SEWERAGE ASSOCIATION

EIGHTH ANNUAL CONFERENCE

Washington, D. C., May 3–4, 1934

The Eighth Annual Conference of the Maryland-Delaware Water and Sewerage Association was held in Washington, D. C., May 3 and 4, 1934. A total of 124 registered at the meeting.

After an address of welcome by Capt. Howard F. Clark, Assistant Engineer Commissioner of the District of Columbia, Mr. Philip O. Maequeen, Superintendent, McMillan Filtration Plant, gave some "Sidelights on the Development of the Washington Water Supply" from the founding of Washington in 1790 to date. "A Booster Pumping Plant for the Washington Aqueduct" was described by J. E. Curtis, Super-

intendent, Dalecarlia Division, Washington Aqueduct. The "Sewage Treatment Plant at Hagerstown, Maryland," was described by H. E. Rhodes, Plant Superintendent. The plant which has recently been placed in operation, consists of grease removal tank, two primary settling tanks, six aeration tanks, a sludge filter building and an office and laboratory building, the total investment approximately $332,000.

The afternoon session was opened with a "Symposium on Water Works and Sewage Projects in the District of Columbia, Maryland, Delaware and Virginia under the Public Works Administration," in which the following took part: J. B. Gordon, Director of Sanitation, District of Columbia; Abel Wolman, State P.W.A. Engineer, Maryland; Roy S. Braden, County Manager, Arlington County, Virginia; R. C. Beckett, State Sanitary Engineer, Delaware; Harry R. Hall, Deputy Chief Engineer, Washington Suburban Sanitary District, Hyattsville, Maryland. Those who took part in the symposium gave in detail the amount of work which has been done by the Public Works Administration in their respective areas. Mr. E. S. Hopkins, Principal Sanitary Chemist of the Baltimore Bureau of Water Supply, presented a paper which had been written jointly with Mr. J. W. Armstrong, Filtration Engineer, entitled "Economics of Corrective Treatment for Cold Water Corrosion." "Interesting Features of New Water Purification Works at Burnt Mills, Maryland" was the title of a paper by Robert B. Morse, Chief Engineer of the Washington Suburban Sanitary District. Mr. A. J. Feeney, Assistant Engineer, Water Department, Wilmington, Delaware, presented a paper entitled "Extending and Modernizing a Rapid Sand Filter Plant at Wilmington, Delaware." Mr. B. E. Beavin read a paper prepared by Mr. R. L. Burwell, Chief Engineer, Annapolis Metropolitan Sewerage Commission, entitled "Sewerage Improvements for the Annapolis Metropolitan Sewerage District, Proposed and Under Construction." The Commission came into existence in 1931 and surveys were begun immediately to secure data for a sewerage system and sewage treatment plant. To obtain a general map of the District without resorting to surveys, arrangements were made for obtaining a map by aerial photography.

The first day's program ended with a dinner followed by an address by W. D. Collins, Chemist-in-Charge, Division of Quality of Water, U. S. Geological Survey, and an entertainment and dance.

Mr. D. M. Radcliffe, Associate Engineer, Dalecarlia Filtration Plant, Washington, D. C., opened the second day's session with a paper entitled "Surge Troubles and Prevention in Pump Discharge Lines on the Washington Aqueduct." "Wrecking the Elevated Water Tank" was presented by Carl A. Hechmer, Departmental Engineer, Washington Suburban Sanitary District, Hyattsville, Md. "Adsorption and Floc-

culation as Applied to Sewage Sludge" was discussed by A. L. Genter, Consulting Chemical Engineer, Baltimore, Maryland. "New Developments in Sewage Treatment and Practice—The Use of Revolving Distributors for Trickling Filters" by W. Allan Darby, Engineer, The Dorr Company, Inc.

At the business meeting the Constitution of the organization was amended to combine the office of Secretary and Treasurer and the following officers were elected for the ensuing year: *President*—C. J. Lauter, Washington, D. C. *First Vice-President*—L. D. Shank, Dover, Delaware. *Second Vice-President*—J. V. Cannen, Hagerstown, Md. *Secretary-Treasurer*—A. W. Blohm, Baltimore, Md. *Executive Committee*—A. M. Tawney, Fort Meade, Md. (4 year term).

Announcement was made that the Ninth Annual Conference would be held in Annapolis, Maryland, in 1935.

Three alternative inspection trips were provided, the first to the new water purification works at Burnt Mills, Maryland; second to the McMillan Park Slow-Sand Filtration Plant and Bryant Street Pumping Station, Washington; and third to the Dalecarlia Rapid-Sand Filtration Plant and New Low-Lift Dam and Pumps at Dalecarlia Lake.

A sight seeing trip which included the White House, Lincoln Memorial, Arlington Cemetery, Lee Mansion, Alexandria and Mt. Vernon, was provided for the wives of members attending the conference.

A. W. Blohm,
Secretary-Treasurer

NEW YORK STATE SEWAGE WORKS ASSOCIATION

SPRING MEETING

Jamestown, N. Y., June 15–16, 1934

The New York State Sewage Works Association held its Spring Meeting at the Hotel Jamestown in Jamestown, New York, June 15–16, 1934, President E. B. Besselievre presiding. One hundred and seven members and guests were registered. Nineteen manufacturers had instructive exhibits attractively set up on the mezzanine floor.

Following registration and inspection of manufacturers exhibits, the convention opened with a brief business meeting and the presentation of two technical papers Friday morning. Henry Ryon, Sanitary Engineer of the State Department of Public Works in his paper illustrated with excellent lantern slides, described the activated sludge plant at the Harlem Valley State Hospital, a very compact plant utilizing Simplex aerators and many automatic mechanical devices. Discussion was opened

by E. M. Jones of the Simplex Valve & Meter Co. and W. B. Marshall of the Chain Belt Company. The paper on the "Present Aspects of Chemical Treatment of Sewage and Sludge" by J. H. Brendlen of the Calco Chemical Co. was of timely interest and the discussion opened by L. L. Hedgepeth of the Penn Salt Co., was followed by many questions from the floor.

At the luncheon, the Hon. Leon F. Roberts, Mayor of Jamestown, cordially welcomed the convention to Jamestown. M. T. Patchin listed the manufacturers exhibits and their representatives and described the products.

Five papers were presented at the afternoon session. A. E. Stilson of the Morse Boulger Destructor Company presented a paper on the "Disposal of Sewage Solids by Incineration," illustrated by lantern slides and charts. The discussion which was opened by Wm. Raisch of the Municipal Sanitary Service Corporation and by W. H. Pitkin of the Oliver United Filter Corporation was followed with considerable interest. The paper by Thomas Heubi giving experiences in "Sewage Treatment at Fredonia" was discussed by A. F. Allen, District Engineer of the State Health Department at Buffalo, who also spoke of recent operating difficulties in handling acid iron wastes at several of the sewage treatment works in the Buffalo area. Earl Devendorf, Associate Director of the Division of Sanitation in the State Health Department, presented a timely paper on the "Status of Federal Aid for Sewerage and Sewage Treatment in New York State" and answered many questions from the floor. A paper on "The Mechanical Filtration of Elutriated Sludge" prepared by C. E. Keefer and presented by Herman Kratz, Jr., of Baltimore, was of unusual interest to all and ably discussed by E. B. Besselievre. Wm. Gavin Taylor of Newark, N. J., presented an "Abstract of Operating Results at Rockville Centre." This paper was briefly discussed by C. C. Agar of the State Health Department.

The evening was devoted to a boat ride on Lake Chautauqua with dinner and dancing at Bemus Point, returning to Jamestown at midnight. Friday afternoon the ladies enjoyed an automobile tour around Lake Chautauqua, including a visit to the Chautauqua Assembly grounds and tea at St. Elmo.

A goodly number attended the now famous sunrise breakfast Saturday morning at which Morris Cohn in his inimitable way conducted a question box and round table and many problems were settled to the satisfaction of all. Leland L. Graham, Director of Public Works, briefly described the Jamestown Sewage Treatment works and the group proceeded to the sewage treatment plant by private automobiles. Here, in addition to going over the plant, they enjoyed an excellent demonstra-

tion, set up by the Oliver United Filter Corporation, of the filtration of sludge conditioned with ferric chloride and lime.

The Fall Meeting of the Association will be held at Oneonta early in October.

RESOLUTIONS ADOPTED UNANIMOUSLY AT THE MEETING OF THE NEW YORK STATE SEWAGE WORKS ASSOCIATION HELD AT JAMESTOWN,

June 15–16, 1934

I

WHEREAS, the N. Y. S. S. W. A. has learned of the retirement of Glenn D. Holmes after many years of outstanding service as Chief Engineer of the Syracuse Intercepting Sewer Commission and in many city, county and state engineering fields, and

WHEREAS, his valuable efforts and wise counsel have done much to advance the status of sewage treatment and of the N. Y. S. S. W. A. which he served in executive capacity.

THEREFORE, BE IT RESOLVED that the N. Y. S. S. W. A. wish Glenn D. Holmes a happy retirement from public service and many years of continued service in public health work.

II

WHEREAS, the N. Y. S. S. W. A. has learned of the retirement of John F. Skinner after over forty years service as Sanitary Engineer of the City of Rochester and

WHEREAS, his untiring efforts and unquenchable enthusiasm have done much to further the growth of the N. Y. S. S. W. A., as President, member of the Executive Committe and other allied activities,

THEREFORE, BE IT RESOLVED that the N. Y. S. S. W. A. wish for him a happy retirement and many years of continued usefulness in his profession of public health work.

III

WHEREAS, the N. Y. S. S. W. A. recommended and actively sponsored legislation introduced before the last session of the N. Y. State Legislature providing for an amendment to the Public Health Law which would have given the Public Health Council authority to establish qualifications for sewage works operators, similar to that which prevails in many other states,

AND WHEREAS the desired legislation failed of passage,

AND WHEREAS the N. Y. S. S. W. A. views this failure of passage as detrimental to public health in N. Y. State,

AND WHEREAS the N. Y. S. S. W. A. believes that the control of operation of sewage treatment works should be vested in the State health authorities,

THEREFORE BE IT RESOLVED that this Association reiterate its hope for the early passage of an amendment to the Public Health Law that will effect control of such qualifications by the State Health authorities,

AND BE IT FURTHER RESOLVED that if power of qualification establishment must be vested in the State Civil Service Commission it should be done in complete cooperation with the State Health Department.

A. S. BEDELL, *Secretary-Treasurer*

Reviews and Abstracts

REPORT OF THE (BRITISH) WATER POLLUTION RESEARCH BOARD FOR THE YEAR ENDED 30TH JUNE, 1933

By H. T. Calvert, *Director*

During the past year, the portion of the working program devoted to wastes disposal and stream pollution has included studies of the treatment of beet sugar and milk factory effluents, the biological oxidation of cellulose and the activated sludge process of sewage treatment, together with the River Tees survey, which has been completed.

Beet Sugar Factory Effluents.—Several hundred strains of bacteria isolated in connection with previous experiments in the biological oxidation of beet sugar factory effluents on large scale percolating filters have been examined for their action on various carbohydrates and on the ammonium salts of lactic, acetic and formic acids. From the results it appears that those species most active with carbohydrates also most readily attack salts of the organic acids; hence, no differential classification is possible on the basis of these two characteristics.

From further laboratory experiments on the effects of adding phosphates to solutions of sucrose prior to treatment on percolating filters, it appears that there may be some advantage in adding the phosphate during the early stages of operation so as to encourage the rapid development of the active biological film.

Milk Factory Effluents.—Laboratory experiments have been made to ascertain whether satisfactory purification of milk wastes can be effected by preliminary storage in a tank to separate fats and protein before biological treatment. The results have indicated that satisfactory purification of washings from churns and factory premises can be obtained by such treatment. Further experiments are required to ascertain the conditions necessary for maximum efficiency of purification. Disposal of the solid matter from the preliminary fermentation and the treatment of wastes containing whey and other milk products also need investigation.

Biological Oxidation of Cellulose.—Cellulose is an important constituent of the organic matter in domestic sewage and certain trade wastes, usually reaching the purification works as suspended matter. During the past year preliminary laboratory experiments on the treatment of suspensions of cellulose by biological filtration and by the acti-

vated sludge process have been carried out. The results have shown that this substance in the form of finely divided wood pulp can be oxidized by biological filters in the presence of sufficient nitrogen. With smaller amounts of added nitrogen, cellulose was deposited in the filter more rapidly than it could be oxidized. Under the conditions of the particular experiments, oxidation by the activated sludge process was not satisfactory.

Survey of the River Tees.—During the past year the biological and chemical observations and experiments planned for the survey have been completed and the first draft of a final report prepared for publication. A brief summary of the whole of this work follows.

In the non-tidal reach above Yarm, the only polluting matter of importance is carried by sewage and sewage effluents. In this section, the rate of natural purification has been found to be influenced to the greatest extent by temperature, increasing rapidly between 10 and 20 degrees Centigrade. Diurnal variations in daylight intensity have been shown to affect the rate of self-purification. The growth of the sewage fungus, *Sphaerotilus natans*, can be correlated with the extent of pollution by sewage and the rate of self-purification. In general the greatest numbers of animals were present during the period April to July, though no significant seasonal variation was observed except in numbers of insect larvae.

Laboratory experiments have shown that undiluted sewage is toxic to trout and that the toxicity decreased as sewage is diluted with fresh water, if the mixture contains sufficient dissolved oxygen. In a 10 per cent mixture, with oxygen at 70 per cent saturation, trout were unharmed after six days. If sewage is allowed to decompose under anaerobic conditions for about three weeks, it becomes very poisonous even after dilution with nine volumes of fresh water, owing to the formation of hydrogen sulphide. The sludge deposited in the river at Croft probably prevents the spawning of salmon.

From Yarm to Stockton, the tidal reach of the river runs between natural banks in an agricultural area. The water in the estuary moves up and down with the flood and ebb tide. Superimposed on this movement is that of the fresh water entering from upstream, largely at the surface. In the middle portion of the estuary, numerous industrial wastes and large quantities of untreated sewage are discharged. The concentration of dissolved oxygen is consequently reduced, especially during the summer months. In addition, the industrial effluents discharged from coke oven plants contain cyanides in sufficient concentration to render the estuary water toxic to fish. Methods of reducing the toxicity of such effluents have been demonstrated. One of the most important results of the survey is that future intallations of coke ovens

to be erected in the Tees area will be designed in such manner that little or no polluting effluent need be discharged.

Sewage Disposal.—In the investigation of the activated sludge process, further experiments have been made on the factors influencing the absorption of dissolved oxygen by sewage. It has been found that samples of sewage sterilized by heating, by filtration through a Seitz filter which removes bacteria, or by certain chemical disinfecting agents, do not take up dissolved oxygen to any appreciable extent. It has thus been shown that bacteria or bacterial enzymes must be present if oxidation of domestic sewage by dissolved oxygen is to occur. In some experiments suspensions of *Ps. fluorescens* were treated with formaldehyde in such manner that the bacterial cells were incapable of growth on agar but their enzymic power was not destroyed, as samples of sterile domestic sewage inoculated with the treated suspensions absorbed dissolved oxygen. These experiments indicate that enzymic activity alone can promote the biological oxidation of sewage. (Abstractor's note: See also THIS JOURNAL, Vol. VI, No. 2, pp. 230–31.)

Additional experiments on the methylene blue test for the stability of sewage have led to further improvements in the method of procedure. By the latest method, the temperature of incubation is 45° C. instead of 22° C., as formerly, and measured quantities of washed sewage sludge and a solution of hydrogen donator such as formate are added. The time required for completing the test is thereby greatly reduced and more trustworthy results are obtained.

The investigation of the colloids of sewage and beet sugar effluents, which has been continued, has included the examination of several types of sewage from the Birmingham area and of beet sugar effluents from the factory at Colwick. These samples have been examined by ultrafiltration, gravity sedimentation and centrifuging at different speeds. A beginning has also been made in a study of the electrical properties of sewage colloids.

In addition to the monthly summaries of current literature prepared by the Board's research staff, certain sections of the experimental work have been described in detail in various papers (listed in an appendix) of which about 30 have been published during the past year.

H. W. STREETER.

FORTY-FIRST ANNUAL REPORT, THE WEST RIDING OF YORKSHIRE RIVERS BOARD (WAKEFIELD, ENGLAND)

By John Garner

The Surveyor, 85, 515–17 (May 11, 1934)

The West Riding of Yorkshire Rivers Board is perhaps the best known and most effective organization in Europe or any other country in administrative control of pollution of streams of an entire watershed. Their annual reports of activities are likewise models of procedure for stream cleaning undertakings operated on the policy of rendering helpful advice and assistance and the use of force only as a last resort. The present report, covering the year ending March 31, 1934, measures up to this standard.

The West Riding is a highly industrialized and densely populated area in which are located such cities as Sheffield, Leeds, Bradford, Huddlesfield, Halifax, etc. There are about 427 sewage works and 900 waste-producing industries discharging effluents, so that pollution problems are complex and varied. The Board maintains administrative headquarters and laboratory at Wakefield and a staff of 22 employees, headed by Mr. J. H. Garner, Chief Inspector. The net expenditures of the Board during the year amounted to £10,600.

Laboratory Activities.—The laboratory examined 2657 samples during the year, the larger number coming from sewage purification works and others from industries, streams and other miscellaneous sources. A considerable number of laboratory experiments have been made on the purification of different kinds of trade waste and abnormal types of sewage in cases where difficulties were being experienced with treatment processes. In some instances improved procedures were demonstrated at the plants for the information and benefit of those in charge. Advice was also given to operators of small sewage works concerning the purchase of laboratory apparatus and in the technique of the more common tests employed.

River Investigations.—A special chemical and biological investigation of the River Holme has been undertaken, a stream heavily polluted with trade waste. The results of this study, when completed, are to be published in report form. Samples of river and back waters were taken at selected locations throughout the drainage area on two separate occasions, both during times of extreme low flows, the detailed analyses of which are presented in tabulated form. Additional examinations were performed to better ascertain the sanitary condition of the water contributed to the Humber as it leaves the West Riding watershed. For lengthy periods the main rivers passing through the thickly populated

centers dwindled to about half the normal volume and a very large proportion of the water consisted of compensation water and sewage plant effluents. The cleaner rivers remained in excellent condition, nevertheless, as witnessed by the fishing and bathing. The amount of pollution carried into the streams by heavy washing rains is of particular importance and is discussed at some length and illustrated by analytical data of a flood water. The resetting of storm water sewer overflows is suggested as a possible aid in reducing this pollution, especially in cases where river water is becoming more and more valuable.

Sewage and Trade Waste Treatment.—Close contact is maintained with the operation and efficiency of sewage and industrial waste treatment plants thoughout the area by means of frequent inspections. Generally, and with few exceptions, the works have been maintained in good condition throughout the year regardless of abnormally low rainfall.

The more important matters concerning sewage purification are grouped and discussed according to catchment areas. The new settling areas and lakes for the filter effluent of the Bradford disposal works have greatly improved the quality of the liquid discharged. The Bradford sewage contains a very large proportion of wool scouring wastes. The first installation in England of mechanical flocculators for increasing the efficiency of chemical precipitants and coagulants in sewage has been made at the Halifax sewage works. The inlet end of one of the sewage settling tanks has been equipped with slowly revolving submerged paddles, illustrated by photographs in the report. Experimental results by this process have shown 15 per cent increase in suspended solids removal, using an acid precipitant. The bioaeration plants at Huddlesfield and Sheffield have produced consistently good effluents throughout the year. The new works at Woodhouse Mill (Sheffield) include the very latest developments in the Haworth process, in which the floor of the channels is sloped and proper circulation obtained in one stage by a specially designed pump instead of by paddle wheels. A general plan of these works and diagram of the axial-flow pump are reproduced in the report.

Of 40 new sources of trade waste pollution originating during the year, all have been either connected to sewers or provided with purification works. The general policy has been consistently followed of encouraging the discharge of industrial wastes to sewers and thereby providing treatment in the municipal plants. Owing to changes in manufacturing processes and products in the textile industries, difficult problems in the treatment of these waste waters have arisen, in the solution of which assistance has been rendered by the Rivers Board. Ferric sulphate was found to be the best coagulating and clarifying agent for the dye wastes from an artificial silk dye works, noting that

the zone of neutrality or slow flocculation of this precipitant (pH 6.5 to 8.5) is to be avoided. The treatment of another dye-waste containing de-sizing refuse was found to be greatly improved when a small amount of fine heavy mineral matter (kieselguhr) was added with the chemical precipitants. A new treatment plan embodying this principle is under construction. Observations on the treatment of other industrial wastes resulting from operations such as hog-killing, beet sugar manufacture, artificial silk and paper making, coal washing, by-product coke and low temperature coal carbonization, and cheese-making contain useful information.

The importance of river gauging is discussed especially in view of the extremely low flows resulting from droughts experienced during the year. Stream flow records in graphic form for several streams under observation are published as insert charts.

Altogether, the report is well worth careful reading by those interested in stream conservation and sanitary control, as illustrative of what may be accomplished by an active Rivers Board.

J. K. Hoskins.

SEWAGE TREATMENT AT SUTTON AND CHEAM *

By William H. Grieves

The two sewage treatment plants of Sutton and Cheam are being enlarged and brought up to date as a result of the rapidly increasing population to be cared for, which now approaches 80,000.

The Sutton Plant at Sutton which handles 1.17 gallons of dry weather flow daily is being remodeled at a cost of about £54,000, including additional percolating filters, settling tanks, dosing chambers, humus tanks, storm water filters and increased pumping capacity.

Two mechanically equipped clarifier tanks 90 × 30 feet in plan and 80 feet deep will provide ten hours detention of the sewage with ultimate d.w.f. of 48,000 gallons per hour. Two Dorreo flocculator units placed immediately ahead of the sedimentation tanks supply an additional hour of detention. This clarifying and flocculating equipment was decided upon after thorough consideration in comparison with additional plain sedimentation or hopper type tanks. It was determined that for purposes of more efficient sludge thickening and digestion, the clarification mechanism excelled.

The *Worcester Park Works* deals with the sewage of Cheam and

* Presented at a meeting of the Institution of Municipal and County Engineers, at Sutton, England, April 27, 1934, and reviewed in *The Surveyor*, 85, 493–94 (May 4, 1934).

other adjacent parishes at the rate of 1.17 m.g.d. of dry weather flow from 45,000 population, estimated ultimately to be 90,000.

The high level plant, constructed in 1930–31 and designed to handle 0.6 m.g.d. of dry weather sewage, consists of the following:

4 detritus tanks	24,000 gals. total cap. or 1/25 d.w.f.
2 sedimentation tanks	290,000 gals. total cap. or 11 hrs. d.w.f.
12 circular sprinkling filters	5′–9″ deep, 14,250 cu. yds. content.
4 humus tanks	80,000 gal. total cap. or 3.2 hrs. d.w.f.
28 sludge beds	2,000 sq. yds. total area.

This plant is already insufficient and is to be duplicated at a cost of £35,000.

The low level plant was constructed in 1927–28 to treat 0.235 m.g.d. of dry weather flow. It is composed of:

1 detritus tank	656 gal. cap.
4 sedimentation tanks	120,000 gals. total cap. or 10 hrs. d.w.f.
4 circular sprinkling filters	6½ ft. deep, 3,630 cu. yds.
3 humus tanks	27,600 gals. total cap. or 2.9 hrs. d.w.f.

After considerable experimentation, chlorine is now used continuously to prevent ponding of the filters. The chlorine is applied to the effluent as it leaves the clarifiers or sedimentation tanks, in quantities varying from 2.5 to 10 p.p.m. and averaging at present 3.75 p.p.m. This treatment has cleaned up the filters and improved the final effluent.

Plans are being developed for a sludge digestion plant at the Worcester Park Works which will treat all the sludge, that from the Sutton plant to be pumped through an 8 inch iron pipe line 1¾ miles long. The sludge digestion tank, 80 feet in diameter and 27 feet deep, will deal with the sludge of 80,000 people and will be provided with gas collection equipment, slow stirring mechanism and warm water coils to maintain the temperature at 80°–85° F. It is expected that the gas produced, which will be sold to the local gas company, will amount to 17 million cu. ft. annually. The digested sludge will be deposited over the land adjoining the works.

J. K. Hoskins

THE REMOVAL OF PHENOLS FROM SEWAGE BY MEANS OF COMPRESSED AIR

By Prof. Dr. A. Schulze-Forster and Dr. L. W. Haase

Gesundh. Ing. **56**, 608, 1933

Experiments have shown that, under suitable conditions, phenols dissolved in sewage may be changed by aeration into insoluble phenols and

that these may be removed from the liquid by filtration. Sewage is best aerated in a tank about 6.5 feet deep, with compressed air, distributed as uniformly and in as small bubbles as possible, through perforated pipes. Enough air must be added to bring the sewage to a strong boil and to thoroughly mix the air and the sewage. Some of the higher phenols, which are viscous, separate on the walls of the tank and form slowly growing crusts, which clog the openings of the aeration pipes. Consequently these pipes must be placed so that they can be easily removed. If a high removal of phenol is desired a secondary treatment is necessary, which is most satisfactory in a shallow tank 1.5 feet deep.

The period of aeration is most important, since both polymerization at high temperatures and oxidation at low temperatures take place during the process. Experiments have shown that, with a very high phenol concentration (over 2.5 per cent) the aeration period is too long to be practical or economical. For example, from sewage containing 2.8 per cent or 2.6 per cent phenol, one hour's aeration at 185° to 194° F., followed by filtration, removed 40 or 41 per cent and two hour's aeration, 51 or 48 per cent. In sewages containing less phenol the efficiency of the aeration was greater. For example, in the sewages containing 1 to 2.3 per cent phenol, 60 per cent was removed in one hour and 70 per cent in two hours. With sewages which contain only 0.15 per cent phenol almost complete removal is obtained by aeration, the decrease amounting to 98 per cent.

Next in importance is the temperature maintained during aeration. In general, if the waste is not hot enough when received, it is treated with steam during aeration in order to obtain a temperature of 158° F. or more, which is necessary to convert phenol to resin. The higher the phenol content of the sewage, the more important is the use of a high temperature. If the sewage is warm enough, treatment with compressed air is sufficient. Since polymerization of the lower phenols to the less soluble condensation products is more rapid at high temperatures than at low, the aeration period is reduced. The most efficient plant is one in which the incoming waste is aerated as hot as possible and cooled during aeration on its way through the clarification plant.

The reaction of the sewage during the course of aeration is also important. Strongly alkaline wastes with a pH value of more than 10 are changed very little during aeration. The most favorable zone for the use of this process is between the pH values of 8 and 10. Sewages slightly alkaline or slightly acid can be treated by aeration only with difficulty. With strongly acid wastes a large decrease of phenol content depends, not on the formation of polymerization products, as is the case with alkaline waters, but on vaporization. A part of the lower

homologs of phenol is quantitatively volatile with steam. If the strongly acid wastes are treated hot, by means of compressed air, complaints from odors in the neighborhood may result. The pH of a number of samples of waste containing 2.3 per cent phenol was adjusted and each was aerated for one hour. At pH 9.8, 61.5 per cent of phenol was removed; at 8.5, 68 per cent; at 7.5, 54 per cent; at 5.0, 38 per cent; and at 2.0, 48 per cent. Apparently polymerization and oxidation of the phenols are more important than vaporization.

The sewage must be filtered in order to remove the insoluble phenols, especially since a greater part of those separated by this treatment are so finely divided that they do not settle well during the limited detention period. Coke the size of a hazelnut or a walnut, built in removable chambers, is satisfactory as filtering material. If it is more convenient to use coarser material, shallow filter basins with longitudinal flow may be employed.

The presence of insoluble material, such as lime, often found in the effluents from ammonia plants, assists in the formation of insoluble compounds. Whether the lime exerts a purely chemical action in addition to absorption has not yet been determined. Apparently the mechanical clarifying action of the suspended matter, comparable with the action of clay suspension, precipitated aluminum hydroxide or iron hydroxide, seems to predominate. In any case, laboratory experiments have shown that the aeration processes are more efficient in sewage containing a certain amount of suspended matter than in clear sewage. For example, in a filtered effluent only 39 per cent phenol was removed after an hour's treatment, whereas in the unfiltered effluent with the same treatment 60 per cent was removed.

G. P. EDWARDS

THE CAUSES OF SEWER GASIFICATION

BY DIPL. ING. K. DAU

Gesundh. Ing. 57, 80, 1934

A questionnaire seeking data about explosions and poisoning from sewer gas was sent out to 50 of the largest German cities. Replies from 43 of the cities furnished the information shown in the following table:

Included in the last column are: chlorine, chloroform, carbon monoxide, carbon dioxide, carbon disulphide, petroleum and ether.

In these cities there were 128 accidents of which 113 were due to explosions and 15 to poisoning. Of these cases 61 per cent were traced to benzine vapor arising, for the most part, from garages, 11.7 per cent

to illuminating gas, 8.6 per cent to methane, 2.8 per cent, each to hydrogen sulphide and acetylene. Since the reports were often based on a guess or on the statement of a worker who was not too expert, the causes in some cases could not be correctly determined. However, it is justifiable to draw conclusions as to the relative danger of the individual types of gas.

	Accidents Through					
	Benzine	Methane	Illuminating Gas	Hydrogen Sulphide	Acetylene	Others
Total	78	11	15	4	4	16
Explosions and Fires	74	9	15	1	4	10
Poisoning	4	2	—	3	–	6
Without Personal Injury	47	3	7	–	1	4
Light Injuries	19	3	4	1	–	6
Serious Injuries	7	4	2	–	3	2
Deaths	5	1	2	3	–	4
Without Property Damage	62	8	10	4	1	10
Slight Property Damage	9	3	3	–	3	6
Serious Property Damage	7	—	2	–	–	—

The formation of digestion gases in explosive mixtures is easily avoided by preventing settled solids from collecting in the sewer and by supplying sufficient air for the removal of the small amounts of gas formed. It is not always possible to supervise the large number of industries which discharge chemical wastes into the sewers but the number of sewer gas accidents may be reduced by preventing the introduction of benzine into the sewer through construction of benzine removers and careful supervision of their operation.

G. P. Edwards

THE CONSTRUCTION OF SEWAGE FISH PONDS AS RELIEF WORK

By Th. Falck

Gesundh. Ing. **57**, 228, 1934

In many cases the use of fish ponds is the most satisfactory method for the purification of sewage. Since good ponds are more profitable than the best farm land, the best land is not too good for this purpose

and poor land can be made more productive in this way. The construction of fish ponds is especially suitable for relief work as it requires a relatively large amount of labor with small amounts of material and without the aid of machinery.

One kilogram of carp contains 30 grams of nitrogen and 11.63 grams of phosphoric acid or a proportion of 2.58 : 1. About 100 to 120 kilograms of plankton are required to build up one kilogram of carp flesh. Fish ponds work over about 60 to 80 times the nitrogen and 40 to 100 times the phosphoric acid content of the fish themselves. Since a one-acre pond will support 243 kilograms of fish containing 7.3 kilograms nitrogen and 2.8 kilograms phosphoric acid, a total of 583 kilograms of nitrogen and 113 to 283 kilograms phosphoric acid are required. The sewage from 202 persons per year contains 591 kilograms of nitrogen and 148 kilograms of phosphoric acid and is therefore adequate for a pond of this size, with perhaps a small addition of phosphoric acid.

If the load is increased so that the sewage from about 810 persons is treated per acre, the excess food material passes out in the effluent from the pond. A large excess of nitrogen is injurious to the fish and retards the purification process. Too much protein and nitrogen cause illness in the carp which can be prevented by the addition of lime and phosphoric acid. Up to the present time, carp have not been successfully raised in a confined space and with artificial food. The growth of plankton, the purification in the fish pond and the yield of fish can be increased by the addition of lime and phosphate.

Two ponds, about 64,500 and 59,000 square feet in area, were used for these experiments. The upper pond discharged into the lower one and the effluent passed into a storm water pond 43,000 square feet in area. The sewage was diluted in the sewer system by ground water to two or three times the dry weather flow. The ponds were filled with sewage in April and 1, 2 and 3 year old tench and 1 and 2 year old carp and eels were added. The flow, which, at first, was only sufficient to replace water lost by evaporation and seepage, was gradually increased to about 800,000 gallons per day. The ponds remained green during this treatment. During the reconstruction of the treatment plant, the flow was again increased with sewage which was often septic. On account of the lack of oxygen, the fish began to die and the ponds lost their green color in a few hours. When the sewage flow was shut off and the ponds were inoculated by a small flow of 250 to 500 gallons per hour, the green color quickly returned. At first, the oxygen consumers *Beggiatoa* and *Sphaerotilus* appeared in the influent channel but disappeared after calcium carbonate was added to the channel and pond. Bone was added to furnish the phosphorus. The microorganisms used this phosphorus and the calcium carbonate without harm whereas an

excess of lime and soluble phosphate was injurious to them. By November the fish looked healthy and had shown an excellent growth. When the tank was drawn down, the bottom of the pond was covered with a 0.4-inch sludge layer which became green in a few days. After the sludge had been washed out by rain, the bottom of the pond was as clean as that of a pure water pond.

It is expected that the sewage from about 2000 persons can be handled by one acre of pond.

G. P. EDWARDS

BUILDING SEWERS UNDER DIFFICULT CONDITIONS

BY F. C. ZIEGLER

Public Works, 65, No. 5, 9 (May, 1934)

One of the most important of the troubles to be encountered in sewer construction is the proper control of sub-surface water conditions; also to secure a firm undisturbed subgrade without loss or shifting of adjacent ground. Tight and substantial trench sheeting, firmly braced, driven well below subgrade, backfilling of cavities outside of the sheeting and storing of excavated material far enough away from the edge of the trench to avoid surcharge are necessary in difficult or deep ground conditions, especially near pavements and buildings. Soft trench bottoms may often be made firm by removing the poor subgrade material and replacing with broken stone, gravel, or tamped cinders, and with a mat of hay below, where water laden shifting conditions occur. Drainage is handled by centrifugal pumps from a sump, with settling boxes where silt discharge is objectionable or, in the latter case, by a system of well points. Crawler pull shovels and convertible cranes with clam shell buckets for trench excavating, and drag line buckets and bulldozers for backfilling in the presence of puddling are commonly used on large sewer work.

Tunnelling construction requires expert planning and execution. In small tunnels practically all work must be done by hand, concrete linings being placed by hand or chuted through holes drilled from the surface. In large tunnels a central mixing plant or transit mixed concrete permits the close regulation and uniformity of output necessary for a properly designed concrete. Facilities for good ventilation, drainage and electric lighting should be provided. Tunnelling in a soft or flowing and shifting material may require compressed air for its successful execution. Steel liner plates, reinforced with alternating steel I beams if necessary, have usually been very satisfactory for temporarily restraining soft or non-self-supporting material in tunnel excavation.

Jacking pre-cast concrete pipes in material other than rock is somewhat successful under suitable conditions. Favorable use of the jacking process usually occurs with small diameter pipe and through short distances. A few of the details necessary to success in jacking pipe are, careful planning with advance information as to soil conditions, use of extra strength pipe, absolute drainage of water to a level below grade, dependable and adequate jacks, and experienced workmen and superintendent. With larger pipes, the use of a steel shield, a part of which controls its direction by means of screws at the advance end of the work appears to have been the most successful method used to maintain true line and grade.

The Westchester Commission's requirements for watertightness are given by E. C. Hallock, Chief Inspector, as follows: An air or water pressure test of 40 lbs. for 24 hours is given all cast iron lines and joints which leak are required to be recaulked or repaired even to the extent of repouring joint if necessary. Reinforced concrete pipes are tested with a minimum of 4-ft. head and are allowed a maximum leakage or infiltration of 1 gallon per hour per inch of inside diameter per 100 feet of pipe over a 24 hour test. In individual joints or 8-ft. sections the maximum leakage must not exceed 1 quart per hour per inch inner diameter. On 15 miles of trunk sewers with an allowable infiltration of 725,000 gallons for 24 hours, the actual infiltration was 86,000 gallons.

R. W. KEHR

SEWAGE DISPOSAL AT FORT ATKINSON, WISCONSIN

BY ROBERT CRAMER

Public Works, 65, No. 4, 8 (April, 1934)

The disposal works, completed February 3, 1934, as a PWA project, were designed to treat 50 per cent above present sewage flows, .42 mgd., varying from .6 mgd. during the day to .2 mgd. at night. Industrial wastes include those from a slaughter house, a sausage factory, several machinery manufacturing plants and a seasonally operated cannery plant which doubles the organic load on the plant when operating.

Treatment consists of coarse screening, primary settling, activated sludge, final settling. The settling tanks are of the rectangular type equipped with Jeffrey sludge collectors. Link Belt Straightline mechanical aerators are used in the aeration tanks. Return sludge is discharged through adjustable draw-offs by gravity to a suction well from which it is lifted by one of two centrifugal pumps so designed that their discharge varies with the depth of sludge in the suction well, thus com-

pensating for rate of draw-off automatically. The return sludge is pumped to an adjustable division box from which part is returned to the aeration tank and part wasted to the digester. Gas is collected and used to drive one of two gas engine generators which floats on the power line and is estimated to supply 2/3 of the power requirements of the plant. The exhaust gases are used to heat the digestion tank and building, supplemented by a coal fired water heater if necessary. If the digestion temperature exceeds 85° F., cold water is automatically admitted to the heating coils. The sludge drying beds are covered with corrugated wire glass with automatic ventilators in the roof, and the sludge bed drains discharge to the plant influent. The digester overflow is treated with lime and discharged into the plant effluent. A single building houses all equipment, laboratory, etc., and has no sewage exposed inside.

R. W. KEHR

DETERMINING THE pH OF SEWAGE SLUDGE

BY MORRILL DAKIN

Public Works, **65**, No. 4, 11 (April, 1934)

At Dayton, Ohio, samples of Imhoff sludge are taken from the riser in the sludge box by means of a pitcher pump let down through the gas dome, or by a stoppered bottle lowered through the slots and filled by pulling the cork when the proper level is reached. The pH is determined colorimetrically by using the supernatant after settling or centrifuging; filtering through ordinary hospital absorbent cotton, either concentrated or diluted 1:10 with a distilled water, pH 7.0; or filtering on a No. 1 Whatman filter paper in a Buchner funnel. The latter method gives pH readings .3 to .8 units higher than the others mentioned. Imhoff sludge is sufficiently well buffered to stand this high dilution without appreciable error in pH determinations. The Imhoff tanks with an average sludge pH of 6.6 gave a gas yielding 19.6 per cent CO_2 and 66.9 per cent methane.

R. W. KEHR

DRYING AND INCINERATION OF SEWAGE SLUDGE

BY ALDEN E. STILSON

Public Works, **65**, No. 5, 15–16 (May, 1934)

Successful and economical sludge incineration seems to necessitate three distinct steps: dewatering to a concentrated filter cake, drying of

the cake to prepare the sludge for firing, and complete combustion of the material. Various types of filters are at present satisfactorily reducing sludge from the original water content of 95 per cent to about 75 per cent. There is enough, or nearly enough fuel value in the sludge to evaporate this remaining moisture if the sludge can be made to give up its heat. High temperature, direct fired, rotary kilns have been used, but attendant odors are a problem.

Recently a drier of the type used for processing salt, coal and ore has been tried. This drier moves the sludge rapidly, in a thin porous bed, through a warm air drying zone and discharges continuously. The apparatus is sturdy and easily controlled, uses large quantities of low temperature air and with 15 to 20 minutes retention period delivers sludge which has not been heated over 120° F.

Nearly three fourths of all low temperature volatiles in sludge are fats of animal or vegetable origin. These are the glycerides of a series of fatty acids, and are non volatile until broken down into glycerol and their respective fatty acids, which are odorous. The use of lime and calcium carbonate can theoretically decrease the odor in fresh sewage sludge through the formation of the calcium salts of these fatty acids. A temperature of 125° F. or greater is required to break down and volatilize the fatty acids and the gases derived from exposure of the sludge to a higher temperature than this should be passed through a zone of 700° F. or better to destroy odors.

The remaining one fourth of the odor-producing substances are largely proteins and albumens which are decomposed by bacteria usually dormant above 95° F. which may be killed by chlorine. Owing to the low boiling points of both methyl and ethyl alcohol, mercaptans should not be formed in the drying process. Odors produced from nitrogenous compounds can theoretically be eliminated by scrubbing.

R. W. KEHR

SLUDGE THICKENING AT PHOENIX, ARIZONA

BY D. TRAVAINI

Water Works and Sewerage, **81**, 107, 1934

A circular tank, 35 feet in diameter, with an effective depth of 9 feet at the periphery of the tank was used for thickening sludge. The thickening mechanism consisted of a picket fence made of 2-inch pipe on 6-inch centers extending 5 feet above the bottom of the tank floor. This was attached to the bracing which supports the bottom scrapers. A skimming arm was also provided. A Sacramento type baffle was

installed at the influent side of the thickener. This structure consisted of a redwood baffle, 24 inches from the wall at the water surface, tapering to 9 inches at the wall, 36 inches above the intersection of the vertical wall and sloping bottom. This baffle was perforated with 4-inch square openings on 18-inch centers. Nine inches in front of these openings, wooden baffle boards 10 inches wide were suspended. Chlorine was added at three points in the tank to retard bacterial activity. Thickening of primary sludge, wasted activated sludge, combined primary sludge and wasted activated sludge, waste mixed liquor, combined primary sludge and waste mixed liquor and digester overflow was tried. Best results were obtained by concentrating mixed liquor whereby the solid content was increased from about 0.2 to about 4.5 per cent. A clear overflow could be maintained when the sludge blanket was within 3 feet of the liquid level.

G. P. EDWARDS

OPERATION OF PRUSS PUMP AT BALTIMORE SEWAGE WORKS

BY C. E. KEEFER

Water Works and Sewerage, **81**, 78, 1934

A sludge digestion tank, which had a capacity of 19,090 cubic feet was equipped with a Pruss sludge circulating pump, driven by a 7.5 hp. motor, operating at 900 r.p.m. The lower end of the suction pipe (11.81 inches in diameter) was placed 24 inches above the tank bottom and the impeller at the top of the pipe was set in such a way that the material pumped was discharged at the surface of the sludge. The top of the sludge or scum was 16 inches below the under side of the roof. A similar tank without a Pruss pump was used for comparison purposes. The results showed that when sludge circulation equipment was used, sludge digestion was not accelerated and the solid content of pipe sludge was much less than in the control tank. Liquefaction of solids was one half as great as in the quiescent tank. Considerably more digested sludge and correspondingless less supernatant liquor were withdrawn. However, the total gas production was increased 21 per cent with only a slight increase in the carbon dioxide content and with less scum formation. The heat losses and the percentage of volatile solids in the ripe sludge were the same in each tank.

G. P. EDWARDS

DEWATERING SEWAGE SLUDGE BY VACUUM FILTERS AT HAGERSTOWN, MARYLAND

By Wellington Donaldson

Water Works and Sewerage, 81, 139, 1934

A mixture of screenings, fresh solids and activated sludge was treated first with about 5.5 per cent ferric chloride (dry basis) to a pH of 4.2 and then with about 9.4 per cent lime (dry basis) to pH of 11.5 before filtration on two vacuum filters manufactured by Filtration Engineers, Inc. The moisture of the filter cake averaged 80.8 per cent and the net yield of dry cake was 1.97 pounds per square foot per hour. The filter cake had no unpleasant odor, contained 71 per cent volatile solids and will be free from offense when spread on land. The cost of filtration per ton of dry solids was $13.74. The cost of chemicals, $7.25, will be reduced when ferric chloride and lime are purchased in carload lots. The lime improves flocculation, tends to give a firmer and drier cake, prevents corrosion of the piping and structures and eliminates putrefactive odors. The use of paper pulp and lime as sludge conditioners had previously been unsatisfactory.

G. P. Edwards

SEWAGE TREATMENT DEVELOPMENTS IN CONTINENTAL EUROPE

By Willem Rudolfs

Municipal Sanitation, 5, 80–84 (March, 1934); 5, 123–124 (Apr., 1934); 5, 159–165 (May, 1934)

The center of interest in sewage treatment in Germany still lies in Rheinland and Westphalia. The five sanitary districts of this region cover a densely populated industrial area with small rivers which are or are rapidly becoming stagnated, thus necessitating the treatment of sewage before discharge into these streams.

The Niersverband was organized in 1929 to care for the drainage area of the Niers River. It covers 455 square miles and has a population of 460,000. Some of the plants existing at the time of organization have since been rebuilt and two new plants at Huls and Keinper have been constructed. The Kempen plant is an activated sludge plant, handling about 210,000 g.p.d. domestic sewage and 260,000 g.p.d. silk dye waste. Experiments with Kremer aerators are being carried out. These aerators are inferior to direct aeration both from the point of

power consumption and effluent produced. At Huls a Mieder clarifier has been in operation for two years. This clarifier developed difficulties in scum removal. Experiments with the use of ferric hydroxide produced by the electrolysis of iron plates are being carried on at Rheydt. The effluent produced by this process was claimed to be clear and the reduction in B.O.D. was said to be about 60 per cent.

In the Emscher district interest centers around the two enormous sludge digestion tanks at Essen-Nord. Each tank has a capacity of 77,600 cu. ft. They are 52.5 ft. in diameter by 58 ft. deep and taper off at the top to a diameter of 23 feet. They are equipped with heating and mixing devices. The supernatant liquor flows into a sedimentation tank which is arranged so that chemicals could be added if necessary. Phenol from the numerous gas works in this district is recovered by distillation and the crude phenol and phenolate sold.

Treatment works to care for the entire flow of the Emscher River were completed about four years ago. The works consist essentially of screens and large sedimentation basins. The overall removal of settleable material by these works is between 80 and 90 per cent.

In the Ruhrverband, the outstanding development is the building of three large lakes for storage and power. The ability of a wide expanse of water to purify itself is used to advantage in these lakes by discharging into them partially treated sewage from a large portion of the population in addition to smaller quantities of raw sewage and trade wastes.

In the Lipperverband experiments are being carried out on a vacuum-trickling filter on the theory (1) that the quantity of air introduced in the ordinary filter is insufficient to completely oxidize the organic material; (2) that the CO_2 concentration in the lower part of the bed is toxic to oxidizing bacteria; (3) the cold air drawn in during winter is detrimental to maximum biological activity. It is claimed that the volume of sewage treated can be increased several times by this method. The author takes exception to this theory based on his experience at Plainfield, New Jersey.

Sewage treatment in Belgium is decidedly lagging. However, a few plants employing activated sludge treatment with mechanical aeration have been built. The largest of these is the Knocke-Zoute plant on the North Sea. In Holland there are some fifty small plants in operation. At Hilversum considerable experimental work on distribution of air by different aeration devices is being done. Also studies are being made on the vacuum-trickling filter idea to determine definitely whether or not such a filter has greater capacity than the ordinary trickling filter.

E. Hurwitz

SEWAGE DISPOSAL IN BRITAIN

By F. Johnstone-Taylor

Municipal Sanitation, 5, 8–10 (Jan., 1934) and 5, 46–48 (Feb., 1934)

British sewage disposal practice is a more or less standardized procedure of tank treatment for settling and digesting sewage solids and purification of the tank effluent on bacterial beds. The large capital investment in sewage works of the general type mentioned above precludes the use of activated sludge which is being adopted, however, when circumstances permit.

The author gives detailed descriptions of the screens in use in Leeds and Birmingham and of the various types of distributors used on bacterial beds.

The tank-bacteria bed method of treatment has given satisfactory results, producing an effluent that can be turned into the comparatively small streams of Britain without danger of nuisance. Sludge disposal in the inland towns is for the most part accomplished by lagooning, air drying and subsequently ploughing under. The seacoast cities barge the sludge out to sea.

E. Hurwitz

CONTROLLING SLUDGE LEVEL

Anonymous

Municipal Sanitation, 4, 374 (Nov., 1933)

Mr. F. A. Hoffman, Superintendent of the activated sludge plant at Morristown, N. J., has successfully employed the photoelectric cell to maintain a constant sludge level in the secondary settling tanks. The device consists of a "Photronic" cell with a light source submerged to a depth of five feet. These units are wired to a sensitive relay which activates electrically controlled valves of the air lifts. By eliminating the human element from control of the sludge level, operation of the Morristown plant has been placed under much better control than was possible before the photoelectric cell installation was made.

E. Hurwitz

CHECKING CORROSION

By R. C. Wilson

Municipal Sanitation, **4**, 375–376 (Nov., 1933)

Aluminum has been employed in a number of installations in several sewage treatment plants as a means toward solving the corrosion problem. Tests by the Aluminum Company of America under exposure conditions selected to cover as wide a range of conditions as possible were made with pure aluminum and some of the more resistant aluminum alloys. It was found that very little harmful effect was produced by the action of gases generated from septic action of sewage or by digestion of sludge. Chlorine in amounts used for odor control and disinfection also had no adverse effect. Specimens immersed in raw, settled, filtered, aerated and final tank effluents were practically unchanged by continued exposure.

E. Hurwitz

SMALL SEWAGE TREATMENT PLANTS

By W. Scott Johnson

Municipal Sanitation, **4**, 335–336 (Oct., 1933)

Neglect and failure to provide some sort of controlled operation for its sewage treatment plant often leads the small municipality into law suits for damages by land owners whose riparian rights have been violated. In addition the life of the plant is materially shortened through deterioration, nuisances and health hazards are created, and valuable information which could be useful in the expansion of the existing plant or the building of a new plant is lost. The common excuse for this neglect is lack of funds, but the author points out that by using the services of the State Health Department and an hour or two daily of the time of one or two men from another department, this excuse is overcome. He gives as examples two small Missouri towns in which the treatment plant is operated under this plan at a very small additional cost to the city and with great benefit to the treatment plant through increased efficiency.

E. Hurwitz

DESCRIPTION OF SEWAGE TREATMENT PLANT AT FLINT, MICHIGAN

ANONYMOUS

The American City, **69**, 46–49 (May, 1934)

The unique feature of the sewage treatment plant at Flint is the design of the four Imhoff tanks. These tanks have a capacity of 4 m.g.d. each and consist of 18 hexagonal cells with the 12 outside cells acting as a structural frame. Sewage enters the tank at the center, divides and flows radially, with a decreasing velocity, toward the outer walls, where it is drawn off through twelve orifices placed around the walls. The argument for an arrangement of this sort is that the very low rate of flow through the sedimentation compartment near the outlets aids in the removal of a larger percentage of the very fine suspended particles than is possible in a tank of constant velocity. Also the gradual reduction in velocity tends to stop eddy currents, thus increasing the settling efficiency. The sludge compartment of each tank is divided, like the flowing through compartment, in 18 hexagonal cells. To provide for more even distribution of solids, openings are cut in the dividing wall. The sludge from the inner ring of cells may be pumped by an air lift to the outer ring. Sludge is drawn by gravity from the outer ring to the drying beds. A capacity of 2.75 cu. ft. per capita is provided in the sludge compartment.

The sludge beds are 24 by 125 ft. in plan and have a total area of 3000 sq. ft. or 0.75 sq. ft. per capita.

The tank effluent is pre-aerated to freshen its condition so that it can be applied at a higher rate to the filter. The filters are designed for a load of 500 lb. 5-day B.O.D. per day per acre-foot and have a total effective area of 3.57 acres.

Provision is made for chlorination of the effluent from the final settling tanks.

The average removal of suspended solids for 1932 was 83 per cent; B.O.D. removal amounted to 78 per cent.

E. HURWITZ

SEWAGE CLARIFICATION AT ROCKVILLE CENTER, N. Y.

ANONYMOUS

The American City, **69**, 43–47 (April, 1934)

Because of the rapid growth in population and increase in sewage flow from 1.25 m.g.d. in 1930 to 3.0 m.g.d. in 1933 it became necessary

to find some way to relieve the overburdened existing activated sludge plant. After preliminary studies the plan to filter the sewage through paper pulp mats on vacuum filters was adopted.

The new filtration plant consists of three 16 ft. long by 10 ft. in diameter vacuum filters, each having a filtering area of 500 sq. ft., and a capacity of 4 gal. per min. per sq. ft. Two of these filters, operated at 70 per ct. submergence, are used for filtering the effluent from the activated sludge plant. The third unit does double duty, that of filtering the effluent from the old primary tanks and dewatering sludges. It can be operated at 60 per ct. submergence for filtering primary tank effluent and 25 per ct. when filtering sludge. All filters are of the "string discharged type" which enables them to operate at a high submergence, making it possible to repulp and reuse the filter cake. In this manner a single charge of paper pulp is used 4 or 5 days, with only a small amount of additional make-up pulp required. The total amount of pulp used is under 400 lbs. per m.g. Pulping is done in a hammer mill. Provision is made for washing the pulp free of ink and reclaiming a large portion of the used pulp. Also provision is made for dosing both the sewage, when necessary, and the sludge with lime.

For sludge filtration about 8 per ct. of the dry weight of the solids of lime and 40 per ct. of paper pulp are added. The sludge cake is discharged with 68 to 75 per ct. moisture and has a B.T.U. value of 7000 to 8000.

The average removal of suspended solids from the activated sludge unit is from 40 p.p.m. to 5 p.p.m. The B.O.D. is reduced by filtration and chlorination from 20 p.p.m. to 5 p.p.m. Bacterial counts are low and 10 c.c. portions show no *B. coli*.

Routine operation has only recently been established, consequently no definite operating costs have as yet been determined.

Detailed description and dimensions of the various units of the plant are given in the article.

E. Hurwitz

TWO PFT ROTARY DISTRIBUTORS

FOR FILTERS 120 FEET IN DIA.

AT

MT. HEALTHY, OHIO

J. S. RAFFETY, SAN. ENGR.

Hamilton County

Our equipment for circular filters includes:

1. Distributors of either mercury seal or air-lock seal types.
2. Four arm or two arm machines.
3. Arms of all standard material.
4. Arms fitted with either orifice jets or deflector sprays.
5. Dosing siphons of all sizes.

We can fulfill practically any specifications for this type of equipment, and our Engineering Department is available for sketches and recommendations.

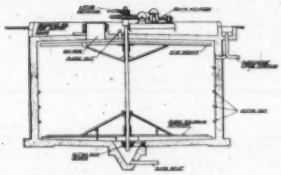
PACIFIC FLUSH TANK COMPANY

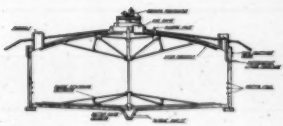
Designers & Manufacturers of Sewerage and Sewage Treatment Equipment

4241 RAVENSWOOD AVE. CHICAGO, ILL.

EXCLUSIVELY SINCE 1893

441 LEXINGTON AVE. NEW YORK, N.Y.





Sludge Digestion Tanks with Girder Supported Roof, or Self Supported Dome Roof

Digestion Tanks with girder supported roofs are to be preferred in small tanks. The cost is low, and the design good, but they cannot be used for large tanks.

For the larger Digestion Tanks the self-supporting Dome Roof design is preferable. It is less costly and it has unusual strength and permanency. It is unique in construction in that steel bands placed around the abutment section are prestressed after the dome is cast, while it is still supported by the framework. By adjusting the stress in the bands, the concrete is placed under compression and no unknown stresses can be set up under varying loads. One such tank actually withstood an earthquake (El Centro, Calif.) without showing any signs of opening or cracking.

A digestion tank roof that won't leak will be gas tight. The gas makes a useful fuel and should be saved for economical reasons. A tight tank prevents fumes escaping, and the possible infiltration of air or surface water. The gas collecting chamber is located at the top of the Dome. Scum breaking arms keep the scum at the top from retarding the movement of the gas to the collecting chamber. As the gas forms, it flows freely to the top of the dome where it is collected and removed with a minimum of moisture or foreign material present.

Digestion Tanks using Hardinge mechanisms to break the scum and dislodge the sludge follow the trend of modern sanitary engineering practice in that they remove the uncertainties in plant operation and aid in plant control.

HARDINGE COMPANY
Incorporated
York, Penna.—Main Office and Works
New York—122 East 42nd Street
Chicago—205 West Wacker Drive
San Francisco—Hardinge-Western Co., 444 Market Street

Hardinge

Clarifying, Digesting and Coagulating Units, Sludge Pumps, Ruggles-Coles Dryers

JEFFREY . . .

for the Latest Developments in Sewage Disposal Equipment

With decades of experience in designing and manufacturing material handling and reduction machinery of all kinds, Jeffrey can offer a diversified line of equipment to handle your sewage disposal problems adequately and effectively.

Sound engineering reasons have dictated the selection of Jeffrey Equipment for many Sewage Disposal Plant installations. Recent plants where Jeffrey has contributed a major share in the efficient operation include those at: York and Lancaster, Pa.; Houston, Texas; Cleveland, Amherst, Akron and Orrville, Ohio; Lake Placid and Saranac Lake, N. Y.; Ft. Atkinson, Wis.; Marietta, Ga.

The most recent developments by Jeffrey are:

- **Improved Mechanically-cleaned Bar Screen, which insures an efficient and thorough screening of sewage. Has a special hinged scraper which prevents jamming of the mechanism from accumulation of foreign material in the bottom of the channel or upon the screen.**
- **A positive Discharge Flight for Sludge Collectors, which dumps through an angle of 90°, thus positively discharging the accumulated sludge in front of the flight into the sludge hopper instead of bringing it to the surface as is the case when the flights are fixed rigidly to the chain.**
- **Screenings Grinder, which actually reduces the screenings to a pulp, which readily passes through the pumps and sinks into the settling tanks. This Grinder does not tear the screenings into long strings or strips that will eventually clog the pumps.**

Jeffrey also builds equipment for Garbage Disposal Plants, Refuse Disposal Plants and Light and Power Plants.

A competent Sanitary Engineer will be glad to work with you and help you solve your Sewage Disposal problems. Write today.

The Jeffrey Manufacturing Company

902-909 North Fourth Street **Columbus, Ohio**

New York, Chicago, Pittsburgh, Philadelphia, Boston, Buffalo, Scranton, Denver, St. Louis, Milwaukee, Dallas, Salt Lake City, Cleveland, Birmingham, Detroit, Cincinnati, Huntington, W. Va., Rochester.

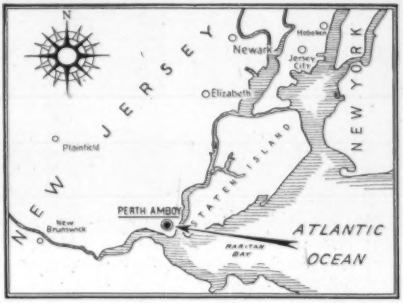
JEFFREY MFG. CO., LTD. OF CANADA

Head Office and Works, Montreal Branch Offices: Toronto, Calgary, Vancouver

For Sewage Disposal . . .

PERTH AMBOY

selects the



LAUGHLIN *Process*

. . . and the plant will be located in residential area!

PERTH AMBOY is a progressive, industrial and residential city of 50,000, located in Middlesex County, New Jersey. Its manufactures include the following industries: metal refining, chemicals, asphalt and oil refining, wire cable, tile and terra cotta production, abattoirs and meat packing.

Perth Amboy has ten sizable industrial plants employing ten to twelve thousand persons.

Perth Amboy's new municipal sewage disposal plant will have an average capacity of 10 m.g.d.—and a maximum of 20 m.g.d. ● The equipment will include 80-foot Laughlin Clarifiers with Magnetite Filters.

● Lime, CALCOAG (Soluble Ferric Sulphate) and Paper will be used. ● Sludge will be handled mechanically through vacuum filters, for direct incineration.

This plant will be *located in a residential area*, adjacent to a city park. Tanks will be without cover. The plant is designed to produce, from domestic sewage and industrial wastes, a CLEAR AND SPARKLING EFFLUENT, sterilized with Chlorine.

No engineer, municipal official or student of public economy should neglect consideration of this new chemical process with regard to any current project.

Plans for the Perth Amboy project, specifications and guarantees covering process and equipment, approved by the NEW JERSEY STATE BOARD OF HEALTH and the NEW JERSEY REGIONAL ADVISORY BOARD. P.W.A. —Consulting Engineer: Louis P. Booz, Perth Amboy, New Jersey.

For further information, write the

FILTRATION EQUIPMENT CORPORATION

Division of AMERICAN CYANAMID COMPANY

SALES OFFICE: 350 Madison Avenue New York

Pasadena, California

September 3-6

SIXTY-THIRD ANNUAL MEETING

American Public Health Association

Write for program and for booklet describing de luxe special train tour

American Public Health Association

50 West 50th Street

New York, N. Y.

For

pH AND CHLORINE CONTROL

GLASS STANDARDS

are always ACCURATE

Noted authorities in the sewage field are using the Hellige non-fading, and therefore permanently reliable, glass standards and handy Hellige comparators, as they offer unequaled advantages.

Complete apparatus $22.50 *and up.*

Write today for detailed information

HELLIGE, INC.

179 East 87th Street, New York, N. Y.

CHEMISTRY IN AGRICULTURE

Edited by

Joseph S. Chamberlain and C. A Browne

This is a cooperative work intended to give examples of the contributions made to agriculture by chemistry.

Each of the sixteen chapters is written by a recognized authority in his own field.

This book is distributed at the cost price of $1.00 per copy for educational purposes.

THE CHEMICAL FOUNDATION, INC.

654 Madison Avenue

New York, N. Y.

The following Local Associations are affiliated with the Federation of Sewage Works Associations:

Arizona Sewage Works Association
California Sewage Works Association
Central States Sewage Works Association
Federal Sewage Research Association
Iowa Wastes Disposal Association
Maryland-Delaware Water and Sewerage Association
Michigan Sewage Works Association
Missouri Water and Sewerage Conference
New England Sewage Works Association
New Jersey Sewage Conference
New York State Sewage Works Association
North Carolina Sewage Works Association
Ohio Sewage Works Conference
Oklahoma Water and Sewage Conference
Pennsylvania Sewage Works Association
Sewage Division, Texas Section, S.W.W.A.
The Canadian Institute on Sewage and Sanitation
The Institute of Sewage Purification—England
The Institution of Sanitary Engineers—England

It is to your advantage to become a member of the local association nearest you. We shall be glad to give you the secretary's name and address.

SEWAGE WORKS JOURNAL

654 Madison Avenue **New York, N. Y.**

:: DIRECTORY OF ENGINEERS ::

FULLER & McCLINTOCK
ENGINEERS

George W. Fuller — Elmer G. Manahan
F. G. Cunningham — W. Donaldson
C. A. Emerson, Jr. — Ernest W. Whitlock
H. K. Gatley

Water Supply, Water Purification, Sewerage, Sewage Disposal, Garbage and Industrial Wastes Problems, Valuations and Rate Investigations.

NEW YORK, 11 PARK PLACE

NICHOLAS S. HILL, JR.
Consulting Engineer

Specializing in Sewerage and Sewage Disposal, Water Supply and Water Purification, Valuations and Reports.
Chemical and Biological Laboratories.

112 East 19th Street New York, N. Y.

GREELEY & HANSEN
Hydraulic and Sanitary Engineers

Investigations and Reports. Plans and Specifications. Supervision over Construction. Supervision over Operation.
Water Supply and Purification
Sewerage and Sewage Disposal
Garbage Collection and Disposal
Valuation and Appraisals

6 North Michigan Avenue, Chicago, Ill.

MORRIS KNOWLES, Inc.
Engineers

Water Supply and Purification, Sewerage and Sewage Disposal, Valuations, Laboratory, City Planning.

Pittsburgh, Pa.

BLACK & VEATCH
Consulting Engineers

Sewage, Sewage Disposal, Water Supply, Water Purification, Electric Lighting Power Plants, Valuations, Special Investigations, Laboratory Service and Reports

Mutual Building, Kansas City, Mo.

METCALF & EDDY
Engineers

Harrison P. Eddy — John P. Wentworth
Charles W. Sherman — Harrison P. Eddy, Jr.
Almon L. Fales — Arthur L. Shaw
Frank A. Marston — E. Sherman Chase

Water, Sewage, Drainage, Municipal
Refuse and Industrial Wastes
Valuations Laboratory

Boston Statler Building

ALBRIGHT & FRIEL, INC.
Engineers

Chester E. Albright — Francis S. Friel
Water Supply and Purification
Sewerage and Sewage Disposal
Industrial Waste and Refuse Disposal
Investigations Valuations Reports

246 South Fifteenth Street
Philadelphia, Penna.

John W. Alvord — Louis R. Howson
Charles B. Burdick — Donald H. Maxwell

ALVORD, BURDICK & HOWSON
Engineers

Water Works, Water Purification, Flood Relief, Sewerage, Sewage Disposal, Drainage, Appraisals, Power Generation

Civic Opera Building Chicago

GEORGE B. GASCOIGNE
Consulting Sanitary Engineer

W. L. Havens — A. A. Burger
F. W. Jones — F. C. Tolles

Sewerage and Sewage Disposal, Water Supply and Purification, Treatment of Industrial Wastes.

Cleveland Leader Building

MEMBERS OF LOCAL ASSOCIATIONS

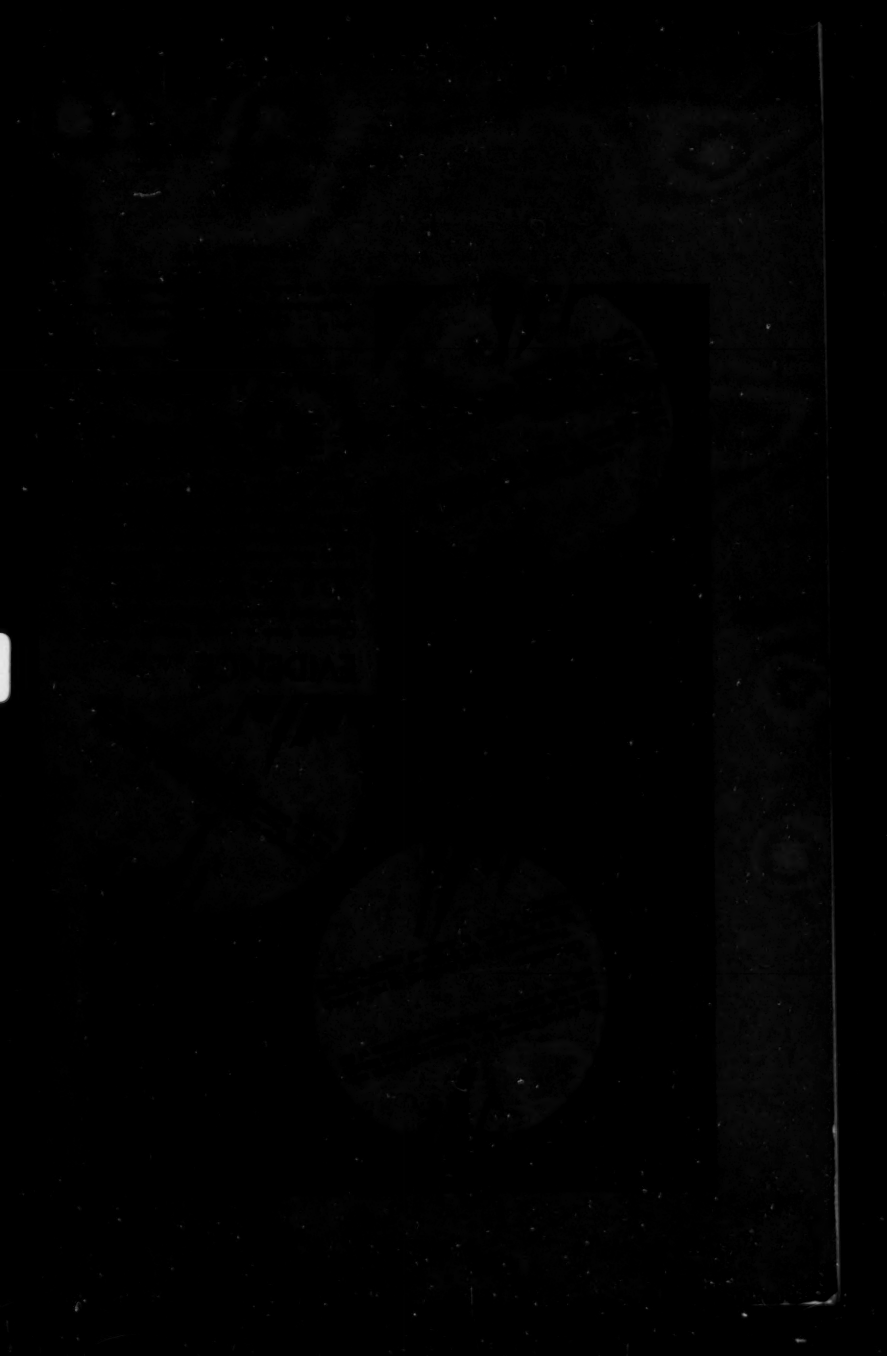
Have you paid your dues to your local association? If not, do so NOW in order that you will receive SEWAGE WORKS JOURNAL without interruption.

CAST IRON MAINS

have infiltration-proof joints

Cast iron mains are proof against infiltration—joints are tight and they stay tight.

Cast iron pipe should be used for any new sanitary lines which will eventually be part of a disposal system.

The Cast Iron Pipe Research Association, Thos. F. Wolfe, Research Engineer, 309 Peoples Gas Building, Chicago, Ill.

INDEX TO ADVERTISERS